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Combustion Efficiency Optimization Manual for Operators of Oil- and Gas-Fired Boilers

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by

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iv

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CONTENTS

		Page
Figures		v
1.	Introduction	1
	1.1 Purpose and general content	1
	1.2 Organization	1
	1.3 Use of the Manual	2
2.	The Combustion Process	3
	2.1 The combustion process and combustion chemistry	3
	2.2 Requirements for complete combustion	4
3.	Boiler Efficiency and Heat Losses	7
	3.1 Heat losses - Fireside	7
	3.2 Heat losses - Waterside	12
4.	Boiler Efficiency Improvement	15
	4.1 Checklists for pre-test inspection, correction, and adjustment of boilers	15
	4.2 Measurement, instrumentation, sampling point, and data requirements for tuning/testing of boilers	18
	4.3 Procedures for achieving low excess oxygen boiler operation	22
	4.4 Burner adjustment	30
	4.5 Maintaining low excess oxygen	31
5.	Maintaining High Boiler Efficiency	33
	5.1 Combustion efficiency spot check	34
	5.2 Boiler operator's log and performance monitoring	35
	5.3 Instrumentation and controls	36
	5.4 Additional considerations in a boiler maintenance program	37
References		39

CONTENTS (continued)

		Page
Appendices		
A	Instrumentation for Flue Gas Measurements	A-1
B	Illustrative Example - Use of Test Data from the Minimum Oxygen Adjustment Procedure	B-1
C	Combustion Efficiency	C-1
D	Tracking Procedure for the Continuing Evaluation of Boiler Performance	D-1
E	Example Inspection/Maintenance Checklists	E-1

FIGURES

Number		Page
1	Variation in boiler efficiency losses with changes in excess O_2	10
2	Variation in boiler efficiency losses with changes in boiler firing rate	11
3	Sample data sheet	21
4	Typical characteristic curves of smoke or CO versus O_2 for oil- and gas-fired boilers	24
B-1	Example data: carbon monoxide (ppm) versus oxygen (%)	B-2
C-1	Combustion efficiency as a function of stack gas temperature and flue gas oxygen content for natural gas firing	C-2
C-2	Combustion efficiency as a function of stack gas temperature and flue gas oxygen content for No. 2 oil firing	C-3
C-3	Combustion efficiency as a function of stack gas temperature and flue gas oxygen content for No. 6 oil firing	C-4
C-4	Comparative relationship between boiler excess air and flue gas concentrations of oxygen and carbon dioxide when burning oil or natural gas	C-5
D-1	Example of Boiler Fact Sheet	D-3
D-2	Example of Boiler Data Record Sheet	D-4
D-3	Example plots of Boiler Tracking Data	D-6

SECTION 1

INTRODUCTION

1.1 PURPOSE AND GENERAL CONTENT

This manual provides general guidance to operators of oil- and gas-fired boilers to increase boiler efficiency, to improve fuel consumption, and to reduce pollutant emissions. Boiler operating principles and suggestions to improve boiler performance are discussed. Combustion is explained in simple terms. Various heat losses are described, and suggestions are given on means to minimize or eliminate heat losses. The manual describes boiler adjustments for peak operating efficiency, optimum fuel consumption, and reduced pollutant emissions. Efficiency, fuel consumption, and emissions are all sensitive to many of the same boiler operating parameters. This manual describes feasible operating techniques and combustion adjustments to achieve clean, safe, and efficient boiler operation.

1.2 ORGANIZATION

This manual consists of five sections. Section 2 is a simplified discussion of the combustion process to provide the boiler operator with a basic understanding of the major factors that affect combustion efficiency. Major topics in Section 2 are the combustion process, combustion chemistry, and requirements for complete combustion. The combustion roles of excess air, fuel-air ratio, and the three T's of combustion (time, temperature, and turbulence) are briefly discussed.

Section 3 examines major heat losses and their effects on boiler efficiency. This discussion, which covers both fireside and waterside losses, explains where these losses occur and how they affect boiler efficiency. Topics in Section 3 include dry flue gas, water vapor, fireside combustible and radiation losses, water quality, blowdown, feedwater losses, and waterside piping losses. The causes, effects, and prevention of these losses are also included.

Section 4 discusses various techniques for improving boiler efficiency, focusing on minimizing stack gas heat loss by testing and adjusting the combustion process for low-excess-oxygen firing. Pre-test inspection checklists are included. These are useful in repairing the boiler equipment to its best possible working condition as a preparatory step to the testing and adjusting procedure. Measurement, instrumentation, and data requirements for testing and adjusting are discussed. The general testing and adjustment procedure is then explained, followed by a discussion of test preparation and test management considerations. A step-by-step procedure to adjust the combustion air is provided to assist operators in achieving improved boiler efficiency.

Section 5 discusses how to maintain high boiler efficiency once it has been attained. Basic tools for monitoring boiler performance are discussed; maintenance of a continuous boiler operator's log is emphasized. Instrumentation for boiler performance monitoring is presented, and suggestions are made regarding data that should be routinely monitored and logged. This section of the manual concludes with a brief discussion of a boiler maintenance program.

1.3 USE OF THE MANUAL

This manual provides simplified guidance to achieve clean, efficient boiler operation. Because of its simplicity the manual has certain inherent limitations so that caution in the use of the manual is required. Combustion controls, burners, and other equipment vary widely in design, complexity, operation, and sophistication. Simplification of information for a manual of this nature does not permit a very detailed engineering discussion of all of the specific equipment and boiler configurations that are available or in use. Therefore, the guidance and procedures that are presented should only be used in conjunction with available technical information and documents for the specific boiler facility. This manual supplements but does not replace or supersede the equipment manuals, handbooks, boiler codes, and other technical documents that apply specifically to a particular boiler facility. Any conflicts between specific information for a boiler and the information in this manual should be resolved before any suggested procedures are implemented.

SECTION 2

THE COMBUSTION PROCESS

A boiler converts available fuel energy to usable energy in the form of steam. The boiler operator's job is to operate the boiler safely and efficiently to optimize the combustion and heat extraction processes and to minimize the emission of air contaminants. An understanding of basic factors that affect combustion is essential to safe, efficient boiler operation. This section is a simplified discussion of the combustion process and the effects of various combustion parameters on the boiler operation.

2.1 THE COMBUSTION PROCESS AND COMBUSTION CHEMISTRY

The oxidation of an element or compound is generally accompanied by a release of heat energy. If oxidation occurs slowly, as in the tarnishing or rusting of metals, heat is generated so slowly that it is lost to the surroundings. On the other hand, combustion is a rapid oxidation process that releases energy that can be harnessed to do useful work.

By volume, air consists of 21 percent oxygen, 78 percent nitrogen, and trace amounts of other gases such as argon and carbon dioxide. By weight, air is 23.2 percent oxygen and 75.5 percent nitrogen; approximately 4.32 pounds of air are required to supply one pound of oxygen for combustion.

Most common fuels consist primarily of compounds that contain carbon and hydrogen. These fuels react rapidly and readily with oxygen to produce heat. Essentially, the hydrogen and carbon contents of the fuel determine its heating value. In the English system the unit of heat measurement is the British Thermal Unit (Btu), defined as the heat energy required to raise the temperature of one pound of water from 59 to 60 degrees Fahrenheit at standard barometric pressure.

2.1.1 Combustion Chemistry

Oxygen combines with the fuel hydrogen and carbon in fixed proportions by weight in accordance with the laws of chemistry. For example the combustion of carbon in oxygen produces carbon dioxide and heat as follows:

C	+	O_2	→	CO_2	+	Heat
12 pounds		32 pounds		44 pounds		169,800 Btu

This equation shows that complete combustion of one pound of carbon requires 2.67 pounds of oxygen (about 11.5 pounds of air); the reaction will also produce 3.67 pounds of carbon dioxide and 14,150 Btu's.

The equation for the combustion of hydrogen in oxygen is:

$2\ H_2$	+	O_2	→	$2\ H_2O$	+	Heat
4 pounds		32 pounds		36 pounds		244,000 Btu

One pound of hydrogen requires 8 pounds of oxygen (34.6 pounds of air) and produces 9 pounds of water and 61,000 Btu.

In the combustion of hydrogen-bearing fuels not all of the liberated heat is recoverable. Since the combustion temperature is relatively high, the water forms as a vapor, and latent heat energy is lost in the flue gas if this vapor is not condensed to recover the vaporization energy. Thus, any fuel that contains hydrogen has a higher heating value (HHV) and a lower heating value (LHV) that differ by this energy of vaporization. For hydrogen combustion the HHV is 61,000 Btu per pound of hydrogen; the LHV is 51,500 Btu per pound of hydrogen. (For carbon the HHV and the LHV are the same since no water is formed.) The HHV's for some common fuels are:

Bituminous (soft) coal	14,000 Btu/pound
Anthracite (hard) coal	12,700 Btu/pound
Number 2 oil	19,000 Btu/pound
Number 6 oil	18,100 Btu/pound
Natural gas	22,800 Btu/pound (1000 Btu/cubic foot)

2.2 REQUIREMENTS FOR COMPLETE COMBUSTION

Four conditions affect the degree of combustion that will occur: fuel/air ratio, turbulence, temperature, and time. The last three are commonly called the three T's of combustion.

2.2.1 Fuel/Air Ratio

The theoretical air requirement to burn any fuel completely can be calculated via combustion equations. This theoretical (stoichiometric) calculation indicates the amount of air necessary to burn a fuel under ideal conditions, leaving no unburned fuel and no uncombined oxygen. If an excess of fuel is provided, not all fuel will be burned; combustion efficiency and heat output will be reduced, and incomplete combustion will result in unburned fuel and lost energy. For example, the incomplete combustion of carbon produces carbon monoxide (CO) - an explosive and toxic gas. The reaction ($2\ C + O_2 \rightarrow 2\ CO$) releases only 30 percent (4350 Btu per pound of carbon) of the available heat in the carbon, and the remaining 70 percent is lost. Incomplete combustion will be accompanied by pollutant emissions (carbon monoxide, smoke, soot, unburned fuel), wasted energy, and potential health and explosion hazards.

If too little fuel is provided the fuel/air mixture is lean (fuel-deficient); boiler efficiency will be reduced because heat will be absorbed by unused air that is discharged from the stack.

Excess Air--

In actual practice more than the stoichiometric amount of air is required to ensure complete combustion. Excess air is necessary for several reasons. One reason is that the mixing of fuel and air is not perfect; therefore, some fuel fails to make contact with oxygen. Also the presence of nitrogen (air is 78 percent nitrogen) tends to inhibit fuel-oxygen contact. To overcome these interferences excess air must be supplied with the fuel.

Excess air is a primary boiler operating variable and a major factor in safe, efficient boiler operation. The required quantity of excess air for a particular boiler depends on factors such as fuel type, fuel composition, boiler design, firing rate, burner design, and burner adjustment. Since the proper fuel/air ratio is a key to efficient boiler operation, the boiler operator should strive to operate with only enough excess air to minimize smoke, carbon monoxide, and unburned fuel.

2.2.2 Turbulence

The proper fuel/air ratio does not ensure complete combustion unless the air and fuel are thoroughly mixed so that every fuel particle comes into

contact with sufficient oxygen to burn it. Turbulence in the combustion zone prevents rich and lean gases from stratifying, mixes the fuel with the air, and promotes complete combustion.

2.2.3 Temperature

In addition to air and fuel, temperature must be adequate for combustion. Each combustible substance has a specific ignition temperature and will not burn until the fuel reaches that ignition temperature. Heat, usually from a pilot flame, is required initially to raise the fuel temperature to its ignition temperature, the temperature at which more heat is released by combustion than is required to sustain ignition. Once ignition has occurred the excess heat ignites surrounding fuel, and combustion continues until one of the three requirements for combustion (heat, oxygen, or fuel) is absent or inadequate. For example if the fuel is not all burned by the time the flame impinges on a cooler surface (boiler tubes, shell or setting), the flame may be cooled below the ignition temperature. Combustion will cease, and some fuel may fail to burn.

2.2.4 Time

Combustion is not instantaneous; time is required to vaporize liquid fuel (or to drive off volatiles from solid fuel), to mix combustibles with air, to raise the fuel to its ignition temperature, and to burn the fuels completely before they cool below ignition temperature. The required residence time for combustible material in the boiler is tied closely to the boiler size, shape, and design. There must be enough space in the boiler's high temperature zone so that combustion is complete before flame cooling occurs.

The three T's of combustion go hand in hand, and each affects the other. Turbulence speeds up liquid fuel vaporization, fuel/air mixing, and contact. Higher temperatures increase combustion rates, promote thermal turbulence and mixing, and decrease the combustion time required.

SECTION 3

BOILER EFFICIENCY AND HEAT LOSSES

It is a fundamental thermodynamic law that energy cannot be created nor destroyed, but the form of the energy can be changed or converted to a different form. As an example a change from chemical to thermal energy occurs during a chemical oxidation (combustion) reaction but the energy quantity before and after the reaction remains equal. As applied to a boiler this means that the sum of all of the energies leaving the boiler (steam, radiant heat, flue gas heat, and other energy forms) exactly equals the energy in the fuel burned. Stated another way:

$$\text{Fuel energy} = \text{steam energy} + \begin{matrix}\text{miscellaneous heat and} \\ \text{other energy losses}\end{matrix}$$

"Boiler efficiency" is a measure of the thoroughness (or efficiency) with which the boiler extracts the available heat energy from the fuel; it is the percentage of fuel energy that is converted to useful heat energy (steam). Stated another way:

$$\text{Boiler efficiency} = \frac{\text{heat output}}{\text{heat input}} = \frac{\text{heat input - heat losses}}{\text{heat input}}$$

Since some heat loss is unavoidable, boiler efficiency is always less than 100 percent (boiler efficiency = 100% - heat losses).

Some heat losses can be minimized or eliminated by proper operating and maintenance practices. Heat losses arise on the heat generation side (fireside) of the boiler and on the heat transfer-extraction side (waterside) of the boiler.

3.1 HEAT LOSSES - FIRESIDE

Four major sources of heat loss on the fireside of the boiler are:

1. Dry flue gas loss - The heat carried out the stack by the hot flue gases. This loss increases with higher stack temperatures and larger amounts of excess air.

2. Water vapor loss - Water vapor in the flue gas comes from the combustion of hydrogen in the fuel and from moisture in the fuel and combustion air. The heat absorbed in changing the fuel moisture to vapor and the latent heat of the product moisture from combustion of hydrogen are lost. This latent heat could be recovered by condensing out the water vapor from the flue gas, but this is not practical because the lower flue gas temperatures necessary to condense the water vapor would also condense acid vapors in the flue gas, causing corrosion of exposed surfaces and reducing plume rise. Therefore the latent heat of the water vapor is not considered to be recoverable.

3. Combustible loss - The combustible loss consists of all combustible material carried away in the flue gas and includes unburned fuel and the products of incomplete combustion. Maladjusted burners and equipment can cause excessive combustible losses.

4. Radiation loss - This heat loss is the heat that radiates through the boiler walls to the boiler room. This loss is fairly constant at all firing rates. Inadequate or deteriorated insulation and furnace wall refractory material increase these losses.

The dry flue gas, water vapor, and combustible losses are all energy losses that leave the boiler through the stack. Stack gas heat loss, the sum of these losses, is the largest single source of lost energy in a boiler; the greatest improvements in boiler efficiency can be gained by minimizing this loss. The magnitude of this loss depends on the temperature and flow of gases leaving the boiler; reductions in either will reduce heat loss and increase boiler efficiency. There are three basic methods of minimizing stack gas heat loss:

1. Use flue gas heat recovery equipment.

2. Maintain clean heat transfer surfaces.

3. Minimize excess air.

Heat recovery equipment such as a combustion air heater or an economizer extracts usable heat so that it is not lost out the stack. An engineering study for each specific boiler is required to determine if such devices are suitable and cost effective.

Soot build-up and slagging on boiler tubes insulates the tubes from the furnace heat and results in decreased heat transfer. As a consequence the flue gas temperature increases, boiler efficiency decreases and the boiler firing rate must be increased in order to maintain a given steam rate. An

excessive build-up of soot on the boiler tubes can lead to: (1) plugging of gas passages between tubes, upsets in boiler water circulation, increased draft loss, and increased fan horsepower requirements; (2) absorption of acid-bearing moisture and corrosion of tube surfaces on the fireside; and (3) metal stress due to high flue gas temperatures, leading to tube leaks and equipment failure.

Firing with minimal excess air decreases stack gas heat loss by reducing flue gas flow and lowering gas velocity through the boiler. As a result boiler tube surfaces are in contact with the hot flue gases longer (increased residence time), and heat can be more thoroughly absorbed. The longer residence time also promotes complete combustion. Thus, the direct result of low excess air firing is improved combustion, lower flue gas temperature and flow, reduced stack gas heat loss and increased boiler efficiency. Conversely, large quantities of excess air require more fuel to generate a given quantity of steam. With excess air extra fuel must be burned to heat the unneeded air, greater amounts of air and combustion gas pass through the boiler, gas velocity increases, residence time decreases, stack temperatures generally rise, stack gas heat loss increases, and boiler efficiency falls. As a rule of thumb boiler efficiency can be increased one percent for each 1.3 percent reduction in oxygen (15 percent reduction in excess air) or for each 40 degree reduction in stack gas temperature. Figure 1 illustrates the effects of changes in excess oxygen on fireside efficiency losses.

Boiler efficiency also depends on the boiler firing rate; significant changes in efficiency occur as the firing rate varies to meet load demand. At low firing rates the radiation loss through boiler walls becomes an increasingly higher percentage of the total heat losses. At higher firing rates the dry flue gas loss increases, generally resulting in higher flue gas temperatures. Figure 2 illustrates how the various efficiency losses are affected by firing rate. For many industrial boilers the highest efficiencies (lowest losses) occur within a firing rate range from approximately 50 to 80 percent of capacity. Obviously, boiler operation in this range is advantageous.

Each boiler has an operating point of maximum efficiency. This is very important at multi-boiler installations, particularly when there are demand fluctuations. For maximum overall efficiency the load should be met by operating units at or near their maximum efficiency points. For example, good

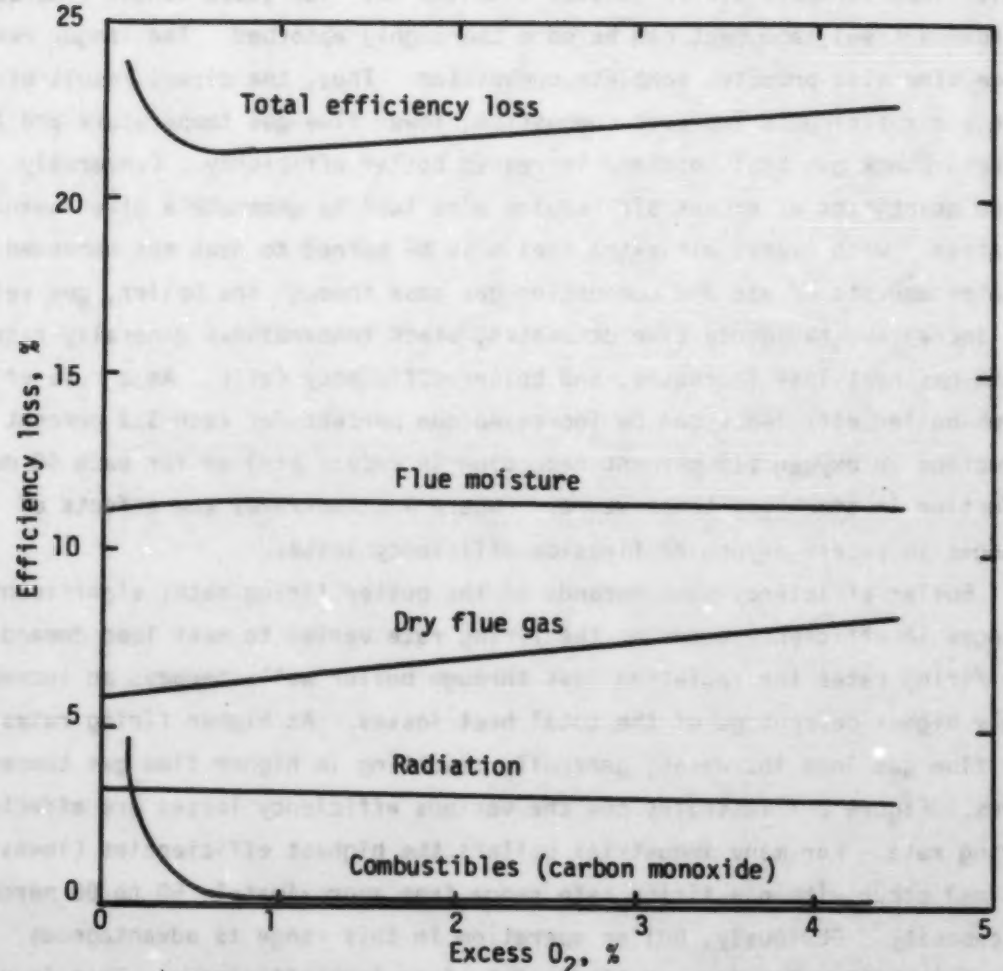


Figure 1. Variation in boiler efficiency losses with changes in excess O_2 (Reference 8).

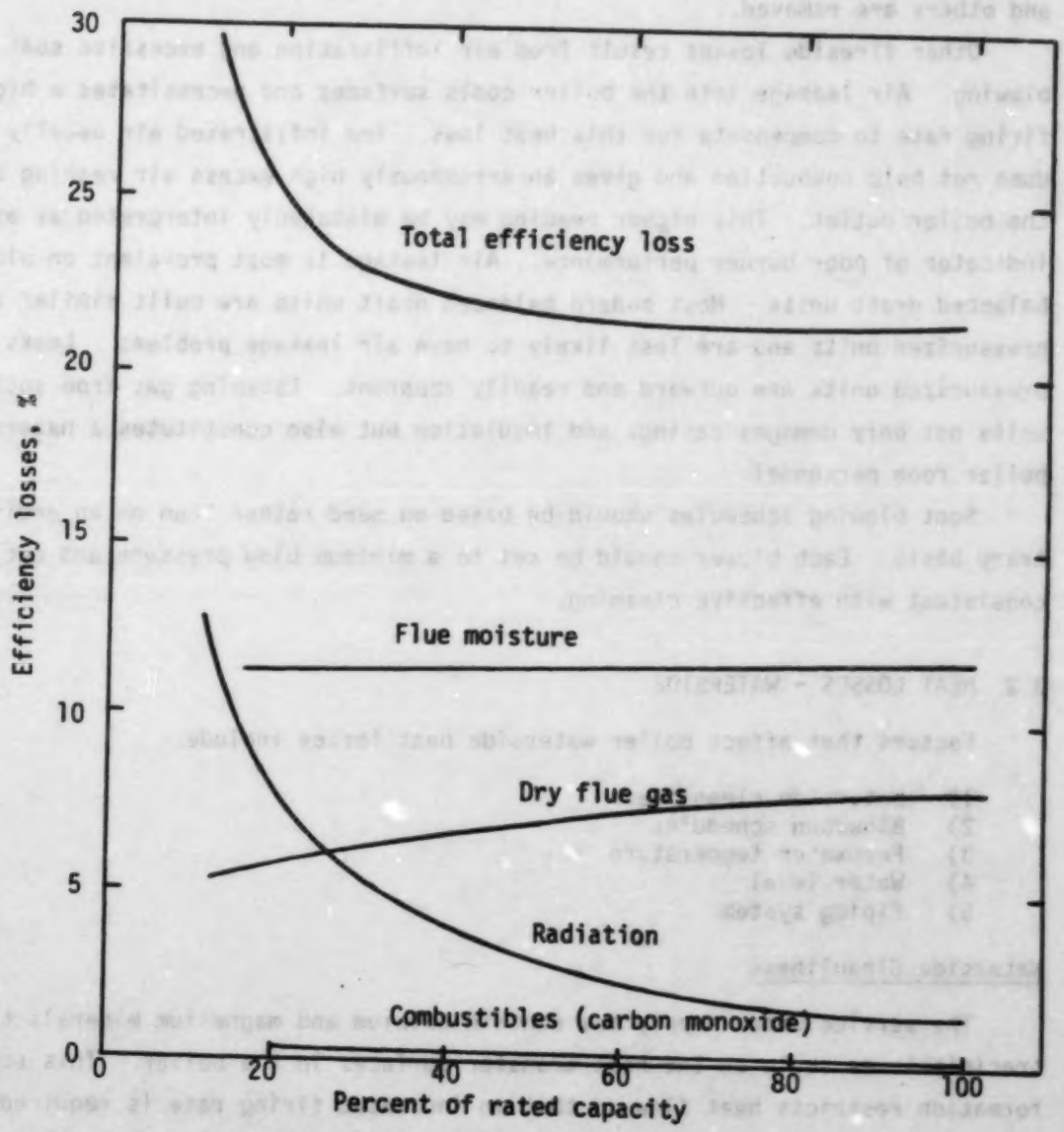


Figure 2. Variation in boiler efficiency losses with changes in boiler firing rate (Reference 8).

load management may require regulating one boiler to meet changes in steam demand while operating all of the others at their individual maximum efficiencies. In order to practice good load management and to achieve maximum boiler plant efficiency the efficiency curves for each boiler must be known, and the points of maximum efficiency must be identified. With this information boiler operators can make appropriate adjustments as some boilers are placed on-line and others are removed.

Other fireside losses result from air infiltration and excessive soot blowing. Air leakage into the boiler cools surfaces and necessitates a higher firing rate to compensate for this heat loss. The infiltrated air usually does not help combustion and gives an erroneously high excess air reading at the boiler outlet. This higher reading may be mistakenly interpreted as an indicator of poor burner performance. Air leakage is most prevalent on older balanced draft units. Most modern balanced draft units are built similar to pressurized units and are less likely to have air leakage problems. Leaks on pressurized units are outward and readily apparent. Escaping gas from such units not only damages casings and insulation but also constitutes a hazard to boiler room personnel.

Soot blowing schedules should be based on need rather than on an arbitrary basis. Each blower should be set to a minimum blow pressure and cycle consistent with effective cleaning.

3.2 HEAT LOSSES - WATERSIDE

Factors that affect boiler waterside heat losses include:

1) Waterside cleanliness
2) Blowdown schedules
3) Feedwater temperature
4) Water level
5) Piping system

Waterside Cleanliness

The service water supply may contain calcium and magnesium minerals that precipitate as scale on the heat transfer surfaces in the boiler. This scale formation restricts heat flow so that an increased firing rate is required in order to maintain a given steam rate. Thus, boiler efficiency decreases. Boiler metal deterioration and corrosion also occur, due to elevated metal

temperatures. Waterside cleanliness can be maintained by proper water treatment and periodic chemical or mechanical cleaning of tube surfaces. Proper water conditioning helps to prevent:

- Corrosion - by maintaining the alkalinity of boiler water at a level (usually at a pH of 10.5 to 11.5) that will neutralize acids and prevent boiler metal attack.
- Pitting due to dissolved oxygen in the water - by deaeration and/or addition of chemicals such as sodium sulfite.
- Hard scale - by use of chemical additives (usually sodium phosphate) to intercept the hardness minerals or by treatment in water softening equipment.
- Sludge deposition that might block tubes, upset water circulation or impair heat transfer. In some cases external filtering and settling may be desirable or necessary. Addition of organic sludge conditioners to boiler water keeps the sludge in suspension for easier blowdown and removal.
- Foaming and carry-over caused by impurities in the water.
- Caustic embrittlement and weakening of boiler steel due to long exposure to a combination of stress and highly alkaline water.

Since varying amounts of hardness minerals are found in almost all water supplies, every boiler plant should have a water treatment specialist available to provide water testing services and to give advice on treatment methods and chemical additives. By intercepting, changing, or neutralizing the hardness minerals and maintaining proper water conditions, adverse effects of waterside scale and corrosion on boiler performance can be minimized, and equipment life and reliability can be enhanced.

Blowdown

Blowdown is used to remove water impurities that can cause scale deposits, priming, foaming, and caustic embrittlement of metal parts. Blowdown water heat losses and the cost of treated boiler water that is wasted can be substantial if the amount of blowdown is excessive. The required quantity of blowdown water depends on the boiler and on make-up water quality. In some cases the potential recovery of energy from the blowdown water may be substantial. Much of the blowdown heat energy can be reclaimed by using heat exchangers to preheat make-up water.

Feedwater Temperature

The temperature of water entering the boiler and the water level in the boiler are two important parameters that affect boiler operation. Higher feedwater temperatures require less fuel to convert water to steam. Heat recovery from boiler blowdown and from condensate streams can be effectively used to raise water temperatures and thus provide fuel savings. An approximate one percent fuel savings results for every 10°F rise in feedwater temperature.

Water Level

Maintaining the water level in the boiler is the most important safety related function performed by the boiler operator. If the water level falls too low heat transfer surfaces can be exposed, and subsequent damage can result. On the other hand, large load swings in a boiler with a high water level can result in water carryover into steam lines, causing water hammer and potential damage.

Piping System

Heat loss from the piping system after the steam leaves the boiler increases the fuel requirement on the boiler. Considerable heat energy is wasted if steam and condensate lines are not insulated or if insulation is allowed to deteriorate. Leaking pipes, fittings, and steam traps incur additional losses.

SECTION 4

BOILER EFFICIENCY IMPROVEMENT

The most significant improvements in boiler efficiency can be obtained by minimizing stack gas heat loss, primarily by reducing the flow and temperature of gases passing from the boiler. The lowest stack losses are achieved when the boiler is tuned to use the least possible amount of excess air consistent with efficient combustion of fuel. Although even a boiler in relatively poor operating condition can be tuned to improve its efficiency and emissions, improvements can be substantially greater if all boiler equipment is in proper repair. Deficiencies discovered during the pre-tuning inspection may not be correctable while the boiler is in service. Problems should be corrected, if possible, before tuning adjustments are made; others should be placed on a maintenance list for correction at the first boiler outage.

4.1 CHECKLISTS FOR PRE-TEST INSPECTION, CORRECTION, AND ADJUSTMENT OF BOILERS

Checklists for the more common items that require attention during the pre-tuning inspection are shown below. These checklists provide a starting point for the boiler operator to use in developing an assessment that is specifically tailored to his boiler facility. The boiler manufacturer's operating and maintenance manual should also be used in conjunction with these checklists to prepare the boiler for tuning and optimization.

4.1.1 Oil Burner Checklist

Inspect to determine that:

- Oil is at the proper temperature for pumping and good atomization (too low or too high preheat temperature can cause poor combustion).
- Atomizer is of proper design and capacity for oil type and burner configuration (a mix-up can occur when tips that have been removed for bench cleaning are reinstalled).
- Oil tip passages and orifices are free of excess corrosion and deposits (poor oil spray pattern can result).

- Burner diffusers are in good condition (not burned or broken), and are located properly with respect to oil gun tip.
- Oil gun is positioned correctly in burner throat.
- Burner throat refractory is intact and undamaged.
- Oil strainers are in place and clean.

4.1.2 Gas Burner Checklist

Inspect to determine that:

- Filter and moisture traps are clean, in place, and operating to prevent the plugging of gas orifices.
- Injection orifices and passages are clear, clean, and free of obstructions.
- Diffusers are located and oriented properly.
- All burner parts are undamaged and in proper position.

4.1.3 Combustion Control Checklist

Inspect to determine that:

- All safety lock and trip circuits are operable (burner controls, feed-pump control, low water cut-off, safety relief valve, flame monitoring systems, fuel shut-off valves, etc.).
- Control linkages operate properly without excess play.
- Fuel supply inlet pressures to all pressure regulators are sufficient to assure constant outlet pressures at all firing rates.
- Pilot and electrodes are clean and adjusted satisfactorily, and electrical signals from pilot flame are proper.
- All fuel valves are internally clean and have proper movement.
- All gauges and metering devices are calibrated and functioning properly.

4.1.4 Boiler Fireside Checklist

Inspect to determine that:

- Tube surfaces are free of excessive deposits and fouling.
- Soot blowers are aligned and operating properly.

- Gas passages and baffles are intact, clear, and free of leaks or bypass.
- Refractory surfaces and external insulation are intact and in good condition.
- Inspection ports are clean and operable.
- Casing, breeching, ductwork, and stack are intact and leak-free.

4.1.5 Boiler Waterside Checklist

Inspect to determine that:

- Water treatment equipment is operating properly.
- Piping system, including the pipe and fittings, safety-release valve vent, water column, blowdown valve, and steam traps are all free of leaks, corrosion, and damaged insulation.

4.1.6 Flame Inspection

Observation of the flame can help to indicate combustion conditions in the furnace chamber. A good flame is difficult to specify, since there are wide variations in burner design that affect flame pattern and appearance. Also, a certain amount of operator preference for a particular flame pattern may be involved. However, flames under low and high excess oxygen firing conditions do have some marked differences. Typically, the difference between low and high excess oxygen firing may include the following:

- Low excess oxygen firing produces a hazy and rolling flame that grows in volume and more completely fills the furnace chamber as it flows somewhat slowly through the furnace.
- Oil firing with low excess oxygen produces a flame that is darker yellow or orange. It may appear partially hazy.
- Gas firing with low excess oxygen produces a flame that is more luminous with yellow or slightly hazy portions.
- High excess oxygen firing produces a flame that is intense, highly turbulent and somewhat compact in appearance.
- Oil firing with high excess oxygen produces a flame that is short, bright and crisp. The flame may be somewhat unstable and may lift away from the burner tip.
- Gas firing with high excess oxygen produces a flame that is compact, hard and bluish-white. The flame may be unstable, lift away from the burner and may have a noticeable roaring noise.

The flame appearance should be checked against the flame color, type, and shape recommended by the burner manufacturer and corrected if necessary for low oxygen firing. Pre-tuning adjustment by an experienced boiler operator will minimize the number of changes necessary during subsequent tuning and testing.

The pre-tuning inspection of combustion conditions should include checks to ensure that:

- The flame does not impinge on any heat transfer surfaces.
- The flame is not distorted (particularly in oil-fired units), which would indicate an obstruction in the orifice or nozzle.
- For oil firing, there are no stars or streaks in the flame.
- There are no odors at the damper, diverter, or observation ports that could indicate poor combustion or insufficient draft.

4.2 MEASUREMENT, INSTRUMENTATION, SAMPLING POINT, AND DATA REQUIREMENTS FOR TUNING/TESTING OF BOILERS

The purpose of the inspection and adjustments discussed in Section 4.1 is to place the boiler in the best possible condition for tuning. The purpose of the optimization tests and attendant boiler tuning is to achieve maximum boiler efficiency, and in so doing to establish performance and measurement standards that reflect efficient operation. Routine spot checks and combustion quality measurements can then be compared with established standards to maintain high boiler efficiency and to detect any deterioration in performance. Frequent spot checks reduce the likelihood that a condition will deteriorate to the point that significant fuel waste and increased air pollution result.

4.2.1 Measurements

Tuning a boiler for low excess oxygen conditions requires three basic measurements:

- Oxygen or carbon dioxide concentration to determine the level of excess air.
- Carbon monoxide to determine the minimum excess air requirement for complete combustion. Stack opacity measurements are also useful in detecting incomplete combustion, particularly for oil-fired boilers.
- Stack gas temperature to determine the stack gas loss.

The measurement of oxygen rather than carbon dioxide to determine excess air is preferred because:

- The relationship between oxygen and excess air is not greatly affected by fuel composition. Carbon dioxide is a product of combustion, and the quantity in the flue gas is dependent on the carbon content of the fuel. Oxygen measurement, on the other hand, is more representative of excess air conditions and is relatively unaffected by the fuel used.

- Instruments for oxygen measurements are generally more reliable and less expensive than those for carbon dioxide. Also, the measurement of carbon dioxide requires much greater precision than oxygen measurement for the same relative degree of accuracy.

4.2.2 Instrumentation

Portable electronic and chemical analyzers can be used for making the oxygen or carbon dioxide and carbon monoxide measurements if the boiler is not equipped with built-in analyzers. Hand-held chemical-absorbing and length-of-stain (color indicator tube) analyzers provide reasonable accuracies when operated by trained technicians using fresh chemicals. Electronic instruments provide high accuracy, require no chemicals, and are available as portable or panel-mounted instruments. A smoke tester and shade scale is useful in evaluating smoke density from oil-fired boilers. A measured sample of flue gas is withdrawn from the stack through a filter paper and the smoke spots are compared with a standard smoke shade scale. Temperature measurements can be made with stem or dial thermometers or other temperature sensors inserted in the stack.

All chemicals and materials should be fresh, and all instruments should be clean, in good repair, and properly calibrated to provide meaningful readings. Additional information on instrumentation is provided in Appendix A.

4.2.3 Sampling (Measurement) Points

The measurement point location must be chosen with extreme care to ensure a representative measurement. Flue gas samples for oxygen and carbon monoxide measurement are especially sensitive to the sampling probe location. Air leakage into ductwork and air preheaters dilutes the gases and gives false indications of furnace conditions. The sampling location should be upstream of the air preheater and any other known leaks.

Gas streams immediately downstream of bends, dampers, or induced-draft fans should be avoided since gases can stratify and give erroneous readings. When a single-point sampling probe is used, several points in the duct should be trial-sampled to find a representative location.

Flue gas temperature measurement is also subject to stratification error; thus, a representative location must be selected. Since heat is lost from the flue gas as it passes through the ductwork and stack, the temperature probe should be located near the boiler outlet to obtain better readings.

4.2.4 Other Measurement Data

In addition to the key measurements discussed above, additional data are necessary to provide a permanent record of boiler operation at the time of boiler optimization and tuning. All data pertinent to boiler operating conditions and stack measurements should be recorded to document boiler efficiency and emission characteristics and to enable future comparisons for the diagnosis of any efficiency or emission problems. Suggested items to be recorded on the prepared data sheet include:

- Boiler identification and fuel used including percent sulfur and fuel grade, test date, and operating personnel
- Steam, feedwater, and fuel conditions (flow rates, pressures, and temperature) to define boiler firing rate and steam generation
- Position of combustion controls and burner settings
- Furnace pressures, temperatures, and damper settings
- Stack measurements (oxygen, carbon monoxide, and temperature) and smoke measurements or observations. Location and position of sample (noted or indicated on a dimensioned sketch)
- Any changes that were made to combustion control or burner settings and any relevant comments on observations of flame appearance or furnace conditions

Figure 3 shows the format of a sample data sheet. Additions or deletions can be made to fit a particular installation; the actual readings to be included will depend on available instrumentation. The data sheet should include all necessary items to define exact boiler operating conditions for future comparisons.

Boiler No.: _____ Fuel: Type/grade: _____

Date: _____ Heating valve: _____

Operator: _____ Analysis: _____

Test No.
Steam flow rate
Steam temperature
Fuel flow rate
Fuel pressure
Fuel temperature
Combustion air temperature
Flue gas temperature
Furnace pressure
Stack pressure
Windbox pressure
Feedwater temperature
Fan settings
Air register settings
Burner positions
Firing rate
Smoke No.
*CO_2 in flue gas and/or
*O_2 in flue gas

Flame appearance: _____

_____

Notes: _____

_____

*Either or both CO_2 and O_2 can be measured.

Figure 3. Sample data sheet.

4.3 PROCEDURES FOR ACHIEVING LOW EXCESS OXYGEN BOILER OPERATION

Under ideal conditions, the minimum oxygen concentration required for fuel combustion is dictated by balanced combustion chemistry equations. However, excess oxygen is required in all practical cases to improve combustion and to allow for variations in combustion controls, fuel properties, atmospheric conditions, and other factors. As excess air is decreased, the oxygen level drops until there is no longer enough oxygen for complete combustion. At this point, there is a relatively rapid increase in unburned fuel and carbon monoxide. This point is commonly called the minimum oxygen level, the smoke limit, or the carbon monoxide limit. Peak boiler efficiency will occur at or close to this level. Unfortunately, operation at this point requires highly sophisticated combustion controls and flame quality monitoring to prevent small changes that could result in unacceptable combustion conditions. Some margin or operating criterion above the minimum oxygen level will be necessary so that normal swings in load and other changes do not produce undesirable conditions. This safety margin depends on load stability and combustion control sophistication. This section presents procedures for determining the lowest practical oxygen level for a particular boiler.

4.3.1 General Procedure

The general procedure for determining the lowest practical oxygen level consists of a test series that establishes the following:

- The initial conditions, i.e., before the oxygen level is adjusted.
- The minimum oxygen level.
- The lowest practical oxygen level where the boiler can be routinely operated, i.e., at an oxygen level that incorporates an adequate operating or safety margin above the minimum level.
- The lowest excess oxygen level that is acceptable during load changes that may occur during normal daily operation.

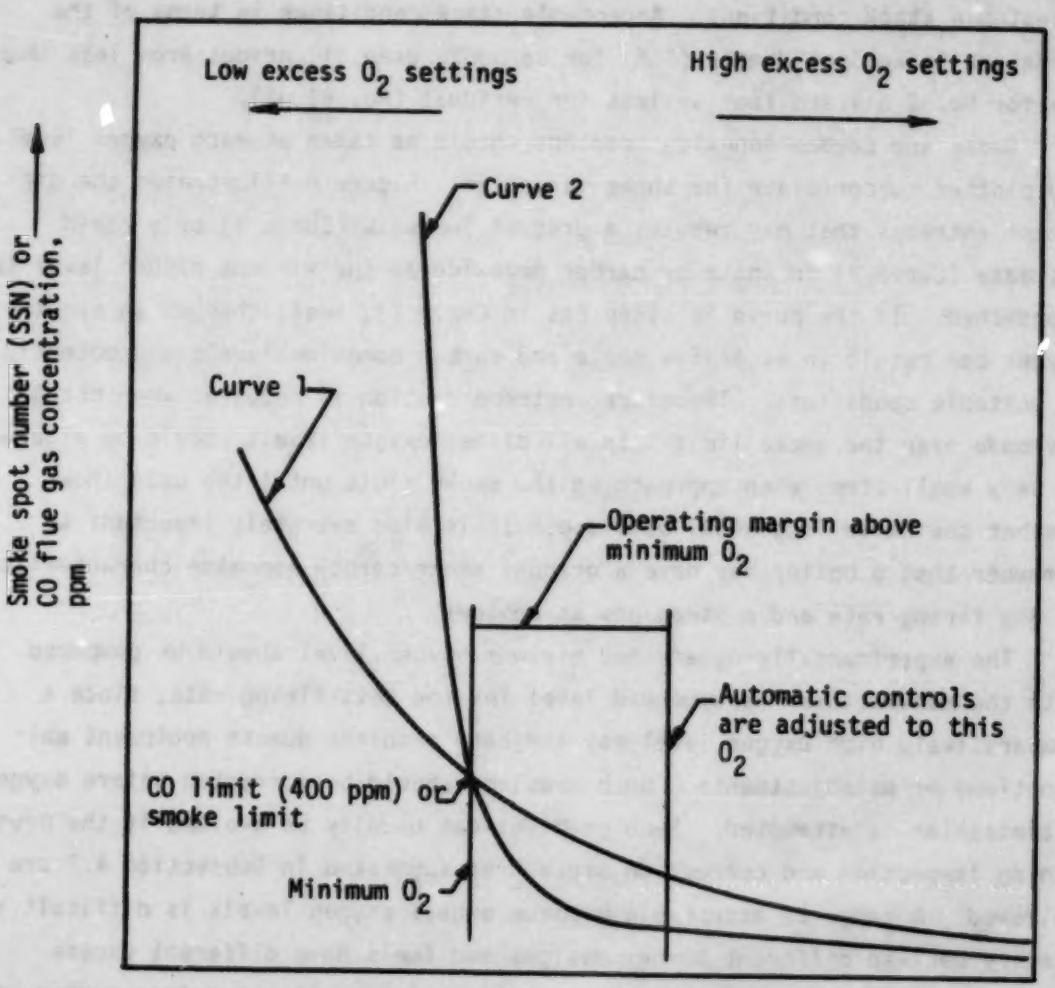
The minimum oxygen level will be determined by raising the excess oxygen level to one or two percent above the existing level and then reducing the excess oxygen in small steps until smoke begins to appear in the case of oil firing, or carbon monoxide emissions rise above 400 parts per million (ppm) in

the case of gas firing. For oil firing, the smoke limit rather than the carbon monoxide limit is used to define the minimum oxygen level, since smoke will generally appear before carbon monoxide emissions rise significantly. The smoke limit for oil firing is the lowest possible excess oxygen level for acceptable stack conditions. Acceptable stack conditions in terms of the Bacharach Smoke Spot Number (SSN) for commonly used oil grades are: less than one for No. 2 oil and four or less for residual (No. 6) oil.

Smoke and carbon monoxide readings should be taken at each oxygen level and plotted to correlate the three variables. Figure 4 illustrates the different extremes that may result; a gradual increase (Curve 1) or a rapid increase (Curve 2) in smoke or carbon monoxide as the minimum oxygen level is approached. If the curve is steep (as in Curve 2), small changes in excess oxygen can result in excessive smoke and carbon monoxide levels and potentially unstable conditions. Therefore, extreme caution is required when changes are made near the smoke limit. In all cases, oxygen levels should be altered in very small steps when approaching the smoke limit until the data show whether the curve is gradual or steep. It is also extremely important to remember that a boiler may have a gradual smoke/carbon monoxide characteristic at one firing rate and a steep one at another.

The experimentally-determined minimum oxygen level should be compared with the manufacturer-recommended level for the test firing rate, since a comparatively high oxygen level may indicate problems due to equipment malfunctions or maladjustments. Such problems should be corrected before oxygen optimization is attempted. Such problems can usually be avoided if the pretuning inspection and correction procedures suggested in Subsection 4.1 are followed. A range of acceptable minimum excess oxygen levels is difficult to specify because different burner designs and fuels have different excess oxygen requirements. Reference 8 suggests that the minimum excess oxygen at high firing rates ranges from 0.5 to 3.0 percent for natural gas and from 2.0 to 4.0 percent for oil.

After the minimum oxygen level is established, the next step is to determine the appropriate oxygen margin or operating "cushion" above the minimum where the boiler can be operated routinely, i.e., the lowest practical oxygen level for the boiler. This operating margin is necessary in order to accommodate the following:


Low excess O_2 settings
High excess O_2 settings
Smoke spot number (SSN) or CO flue gas concentration, ppm
Curve 2
Curve 1
Operating margin above minimum O_2
Automatic controls are adjusted to this O_2
CO limit (400 ppm) or smoke limit
Minimum O_2
PERCENT O_2 IN FLUE GAS

Curve 1 - Gradual smoke or CO vs. O_2 characteristic
Curve 2 - Steep smoke or CO vs. O_2 characteristic

Figure 4. Typical characteristic curves of smoke or CO versus O_2 for oil- and gas-fired boilers.

- Rapid load swings that can cause incomplete combustion if an adequate margin is not provided.

- Non-repeatability or normal play in automatic controls. (Poor repeatability or excessive play can be determined by repeating a firing rate from both the high and low sides while allowing fuel and air controls to function normally and then comparing excess oxygen levels after the boiler is stabilized. Excess oxygen should repeat within a few tenths of a percent. Excessive play suggests inspection of the control system for tolerance problems in air dampers, control shafts, valve cams, controllers, etc., and correction of any problems that are discovered.)

- Normal variations in atmospheric conditions. (For boilers not equipped with temperature/pressure compensation systems, extreme variations in atmospheric conditions can cause excess oxygen changes of one percent or more.)

- Fluctuations in fuel properties that modify excess oxygen requirements.

Typical margins above the minimum oxygen level may range from 0.5 to 2.0 percent, depending on the control system and fuel characteristics at a particular boiler (Reference 8).

Lowest practical oxygen determinations should be made for several boiler firing rates. The optimum excess oxygen level should be determined at several firing rates within the boiler's operating range. A sufficient number of determinations at different firing rates should be made to assure that after the final control adjustments are made, the optimum oxygen conditions are maintained at all intermediate firing rates. Some compromise may be necessary to select a final oxygen level that gives good performance over a range of firing rates. If the boiler is used at only one particular firing rate, it should be set to optimize conditions at that rate.

4.3.2 Test Preparation and Management Considerations

Pre-test planning and preparation ensures that the optimization tests and adjustments proceed smoothly and produce meaningful results. A test plan should be developed which outlines the procedures, participants, boiler operating and test conditions.

Advance planning and preparation should address the following:

- Manpower requirements. Sufficient personnel must be available to continuously monitor controls, instrumentation, flame appearance, and stack conditions during adjustments so that simultaneous data measurements can be made.

- Instruction. All participants should be instructed in advance regarding the test purpose and the respective roles of each participant during the test.

- Instrumentation. All required instruments and metering devices should be checked for proper operation well in advance of each test so that necessary parts replacement and repair can be completed. Instruments, etc. should then be calibrated and tested.

- Test measurements and data records. The optimization procedure focuses on the measurement of incremental changes in firing conditions due to changes in the oxygen supply to the boiler. Accordingly, proper measurements are necessary to produce meaningful test results. Monitoring personnel should be given pre-test instruction which stresses the importance of proper timing and technique in making and recording test measurements, readings, and observations. Personnel should be instructed to record the data only during stable boiler conditions and to make all readings and observations simultaneously (on command). Additionally, data record forms should be prepared in advance and personnel instructed in their use and purpose.

- Boiler manuals. The operation and maintenance manuals for the boiler and boiler equipment should be assembled, and pertinent sections should be marked for quick reference during the boiler tuning/adjustment. The manuals should be reviewed for apparent conflicts with the adjustment procedures outlined below. Such issues should be resolved before starting these procedures.

- Steam service disruption. The firing rate will usually be controlled manually during the tests to obtain stable conditions and constant steam pressures. Depending on the firing rate, the quantity of steam generated may be more or less than the steam demand. Where other boilers are available, the loads on those boilers should be modulated to meet system demand. Otherwise, prior arrangement and planning are necessary so that excess steam can be dumped during high firing conditions and/or steam service can temporarily be disrupted during low firing conditions.

4.3.3 Safety Related Considerations

The step-by-step procedures presented here are generally applicable to low excess oxygen firing of oil- and gas-fired boilers. However, combustion controls, burners and other furnace and boiler equipment vary widely in design, complexity, and capacity. Therefore, it is recommended that the procedures be supplemented by and be used in conjunction with technical documents such as local/national boiler safety codes, air pollution regulations, operation/maintenance manuals, and other documents supplied by boiler equipment manufacturers. These documents should be examined and compared with the suggested procedures and any apparent conflict between codes, boiler equipment

manuals, and the guideline procedures should be resolved before the procedures are implemented. The procedures should be modified as necessary to accommodate any special facility requirements and both the procedures and test plan should be specifically tailored to the facility.

It is emphasized that the optimization procedures are not intended to replace or supercede any procedures or requirements that are necessary for safety reasons. Manufacturers' recommendations should be followed and local and national boiler safety codes must be observed at all times. Safety must never be compromised in boiler operation and it is therefore appropriate to stress the safety aspects of implementing low excess oxygen operation.

Safety and the Optimization Procedure

With the boiler in good operational condition and all pre-test planning and preparation completed, the tests and adjustments to achieve low excess oxygen firing can begin. Caution is the key word in applying this or any other combustion modification procedure.

Pre-Test Safety Checks--

Immediately prior to initiating the procedure, checks and observations should be made to ensure that:

- All boiler safety interlocks and trip circuits are operable and functioning properly.
- Pilot lights and electrodes are adjusted satisfactorily.
- Fuel pressures and boiler water levels are within acceptable operating ranges.
- Flame color and shape indicate satisfactory combustion conditions.
- Boiler operation and firing conditions are stable.

Safe Conduct of the Optimization Procedure--

During the oxygen optimization procedure:

- Know at all times the impact of any adjustments on fuel flow, air flow, or the control system.
- Be alert for any changes in boiler settings or changes in fuel pressures/properties that might affect the flow of air or fuel to the burner and produce uncontrolled shifts in excess oxygen.
- Exercise extreme caution when making oxygen changes near the smoke or CO limit. Do so in very small steps. As the minimum oxygen

condition is approached and/or reached, unpredictable and potentially unstable conditions can occur with small oxygen changes. For purposes of testing, occasional CO levels of up to 1000 or 2000 ppm can be acceptable provided adequate and attentive boiler monitoring and flame observation is made to assure stable conditions. Further reduction of the excess oxygen results in very rapid increases in CO and other combustibles which can lead to flame instability, furnace pulsation, and boiler explosions. Remember, a boiler may exhibit a gradual change at one firing rate and have a rapid change at another.

- Control system adjustments while operating at low loads is not recommended. Air flow requirements at low-fire conditions usually are dictated by flame ignition characteristics and stability rather than by combustion efficiency.

- Do not reduce air flow by throttling the burner air registers. This alters the fuel/air mixing characteristics and complicates the tests.

- Observe and maintain the proper water level in the boiler. If the water level falls too low, heat transfer surfaces can be exposed and boiler explosions or other damage can result.

- Watch boiler instrumentation closely while making any changes and frequently observe the flame appearance as an indicator of combustion conditions.

4.3.4 Step-by-Step Procedure for Low Excess Oxygen Operation (Reference 8)

1. Operate the boiler at the desired firing rate with combustion controls in the manual mode. Make sure that all safety interlocks are still functioning. Mark the linkage setting in order to retrace the direction and position of the adjustments.

2. After the boiler has stabilized, observe flame conditions and take a complete set of boiler and stack readings. This will establish the existing operating conditions at the particular firing rate. If the excess oxygen is close to the lower end of the range of typical minimum oxygen values (Section 4.3.1), and if carbon monoxide and smoke are at acceptable levels, it is quite possible that the boiler is already operating near the optimum excess oxygen at this particular firing rate. It may still be desirable to proceed through the following steps to determine whether lower excess oxygen levels are practical. In any event, do not assume that oxygen settings at other firing rates are also close to the optimum.

3. Increase excess air until the stack excess oxygen has increased by one or two percent. Take readings after the boiler has stabilized and note any changes in flame conditions.

4. Return excess air to the normal level and then slowly reduce the excess air in small steps. Watch the stack for smoke, and constantly observe the flame. Take a set of stack readings following each change. Watch out for low windbox/furnace pressure emergency shutdown safety interlocks ("fuel trip" set points) at low firing rates.

5. Continue to reduce the excess air stepwise until one of the following limitations is encountered.

- Unacceptable flame conditions such as flame instability or flame impingement on furnace walls.
- High carbon monoxide content in the flue gas. In normal operation the carbon monoxide should not exceed 400 ppm, but levels up to 2000 parts per million are tolerable during the test. Use caution since carbon monoxide can increase very rapidly with small changes in excess air.
- Smoke. Do not confuse smoke with water vapor, sulfur, or dust plumes which are usually white or gray in appearance. Smoke spot readings should be less than one for No. 2 oil and less than four for No. 6 oil or coal.
- Equipment related limitations such as low windbox/furnace pressures or built-in air flow limits.

6. Obtain carbon monoxide, oxygen, and smoke readings to establish curves similar to the samples shown previously in Figure 4. Plot the data on graph paper.

7. The minimum excess oxygen requirement for the boiler was determined in Step 6, but do not adjust the burner controls to this value. Although this may be the point of maximum efficiency, it is probably impractical to operate the boiler right on the combustible or smoke threshold.

Compare the minimum oxygen requirement to the value recommended by the boiler manufacturer. Typical values for various fuels are given in Section 4.3.1. If the minimum oxygen requirement is substantially higher than the manufacturer recomendation, further burner adjustments may allow operation at lower oxygen levels.

8. Establish an excess oxygen margin to accommodate fuel variations, load changes, and atmospheric conditions. Reset the burner controls to maintain this excess oxygen when operating in the automatic control mode.

This is the lowest practical excess oxygen for the boiler at a particular firing rate. The boiler efficiency at this condition is as close as practical to peak efficiency, which usually occurs near the minimum excess oxygen.

9. Repeat Steps 1 through 8 for each firing rate to be tested. For some control systems it will not be possible to set the optimum excess oxygen at each firing rate since control adjustments at one firing rate may also affect conditions at other firing rates. In this case, use judgment to select a setting that gives good performance throughout the range of firing rates. Repeated tests may be necessary. If the boiler is operated at one predominant firing rate, the setting should be made to optimize conditions at that rate, allowing for acceptable firing at other rates.

10. After the control adjustments have been completed, verify that the new settings will be acceptable during all load changes that may occur. While making rapid load swings, observe the flame and stack to preclude any unacceptable conditions. Utilize stack continuous monitors (oxygen, carbon monoxide, opacity) when available. If undesirable conditions are detected, reset the combustion controls to provide slightly more oxygen at the particular firing rates. Verify these new settings in a similar fashion. Document the selected control settings for future reference.

11. Adjustments at or near low-fire conditions may not be advisable. Excess air requirements at these conditions are usually dictated by flame ignition characteristics and stability which can be critical and difficult to evaluate.

12. When an alternate fuel is fired, perform the above tests and adjustments for the second fuel. In some cases it may not be possible to achieve optimum combustion of both fuels at all firing rates. In these cases, a compromise must be made, and judgment must be used to select the best conditions for normal firing rates.

Appendix B shows by example how the data obtained from the above procedures are used to define the lowest practical oxygen level for safe, efficient combustion. Appendix C presents methods for calculating combustion efficiency improvement and fuel savings resulting from adjustment for low excess oxygen firing.

4.4 BURNER ADJUSTMENT

The above procedures should result in setting the boiler for low excess oxygen operation over the entire boiler operating range. Other measures to attain minimum oxygen requirements include burner control and fuel system adjustments. Since burner design and combustion controls vary widely, it is

not practical in this general document to provide detailed procedures for the many systems in use. It is assumed that boiler operating personnel know their specific burner systems and controls. Additional information should be available in the boiler operations and maintenance manual or from the boiler manufacturer, combustion specialists, and plant engineering staff.

Burner adjustment is essentially a trial-and-error procedure; general precautions for the above oxygen optimization procedure should be followed. As adjustments are made the stack, flue gas, and flame conditions should be monitored closely along with the measurements of oxygen, carbon monoxide, smoke and temperature to indicate whether the burner adjustments produce the desired effects. Burner adjustments should be made slowly in small steps, and adequate time must be allowed for boiler conditions to stabilize before evaluating each change. Special attention should be given to changes in burner settings or fuel properties that might affect flame stability, flame impingement and shifts in excess oxygen levels. The boiler manual may give additional information on the range of allowable adjustments.

4.5 MAINTAINING LOW EXCESS OXYGEN

Maintaining low excess oxygen requires conscientious effort by boiler operator personnel, especially during the first several months as experience is accumulated for new operating procedures. Special attention should be given to combustion conditions. For example changes in oil properties, burner settings, control system settings, damper operation, air heater performance, etc. may alter fuel/air ratio and excess oxygen levels. Further burner adjustments may be necessary if tube fouling or flame problems develop. The operator should keep track of boiler maintenance requirements and should thoroughly inspect the burner and furnace surfaces during each boiler outage.

One of the best aids in maintaining low excess oxygen is a periodic spot check of combustion quality. Stack measurements of oxygen, carbon monoxide, smoke, and temperature should be taken and compared with the "baseline" readings that were recorded at the same firing rate during the tuning procedure described in Step 8.

SECTION 5

MAINTAINING HIGH BOILER EFFICIENCY

The benefits of boiler adjustment can only be realized if steps are taken to insure that any improvements in boiler efficiency, fuel consumption and emissions are maintained. Boiler maintenance should focus on every problem that may degrade boiler performance: e.g., an increase in the temperature, flow rate, or combustible content of the flue gas; an increase in convective or radiant heat losses from the boiler shell, ductwork, or piping; or an increase in blow-down requirements. The discussion of boiler efficiency and heat losses in Section 3 and the pre-tuning inspection checklists in Section 4 both emphasize efficiency-related maintenance items.

Boiler maintenance has both corrective and preventive aspects. Corrective maintenance is generally performed on an as-required basis whenever efficiency falls below preset standards. On the other hand preventive maintenance consists of periodic cleaning, replacement, and adjustment activities to reduce the chances of equipment failure or performance deterioration. Preventive maintenance should reduce the frequency and need for corrective maintenance, but it will not totally eliminate corrective maintenance requirements. An effective maintenance program uses both preventive and corrective procedures to maintain efficient boiler performance.

Basically a maintenance program should routinely monitor the boiler operation to identify boiler system deterioration and any deviations from desired performance standards. This requires regular performance measurements and routine checks for leaks, faulty controls, damage to insulation or refractory, and other heat losses. These routine observations are compared with specifications to determine the need for maintenance.

Two basic tools can be used together effectively in an efficiency-related maintenance program. The first is the routine combustion efficiency spot check which can provide an early indication of any efficiency-related problems. The second is the boiler operator's log that documents trends in boiler condition and performance.

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5.1 COMBUSTION EFFICIENCY SPOT CHECK

Stack measurements of oxygen, carbon monoxide, smoke, and temperature establish instantaneous combustion conditions that can be compared with "baseline" standards that reflect optimum boiler adjustments (Section 4.3.3, Step 8). The stack measurements should be conducted under steady boiler operating conditions. A log or plot of day-to-day data shows trends and helps to identify the cause and severity of any combustion efficiency change. Depending on the instrumentation available, combustion efficiency spot checks should be conducted weekly, daily, or even more frequently to reduce the likelihood that problems will develop that result in fuel waste and pollutant emissions. The routine and periodic combustion efficiency spot-check can be incorporated into a systematic tracking procedure from which trends in boiler combustion efficiency and operating parameters can be noted. A tracking procedure to monitor, track, and note trends in boiler performance indicators is presented in Appendix D.

A change in the excess oxygen level may indicate air or fuel supply problems or a change in oil properties. Excessive tube fouling, plugged air passages, air leaks, deteriorated furnace baffling, or changes in atmospheric pressure can cause shifts in oxygen levels. High excess oxygen levels may indicate air leaks, low fuel pressure, or a control system malfunction. Low excess oxygen values suggest improper control system operation or an insufficient air supply. If the oxygen is normal but the smoke or carbon monoxide readings are high there may have been changes in fuel characteristics or burner-related problems. For oil firing the cause may be improper viscosity or fuel temperature; worn or carbonized burner tips, diffusers, or spinner plates; poor atomization; or other fuel/air supply problems. For gas firing a dirty burner is a possible cause; in multiburner installations there may be unbalanced fuel/air distribution between burners. A 20°F increase in stack temperature without a corresponding change in excess oxygen, carbon monoxide, and smoke may be a preliminary indication of furnace baffle deterioration, fouled tubes, or a soot blower malfunction.

The above examples illustrate only a few of the common causes of deteriorating boiler performance and their relationship to spot check measurements. Other causes may also contribute to boiler efficiency deterioration. It is important to emphasize that the primary purpose of the combustion spot check is to provide early warning of an impending efficiency-related problem so that

further action can be taken to correct the problem before fuel waste or extensive maintenance is required. The spot check indicates possible causes, but it does not diagnose a combustion-related problem precisely.

5.2 BOILER OPERATOR'S LOG AND PERFORMANCE MONITORING

The boiler operator's log is the primary tool for determining the need for maintenance to restore performance and efficiency. The log documents the condition and performance of the boiler and provides data to document trends as a function of time. Performance trends can be used to determine deviations from performance standards and to establish maintenance procedures. Comparison of daily log data with specifications may indicate the need for specific maintenance. The data provide useful information for various performance and efficiency checks, for identification of equipment problems, for diagnosis of problems, and for maintenance scheduling.

Specific items on the log sheet and the frequency at which data are recorded depend on the size and complexity of the boiler installation. All measurements should be made during steady load conditions because data taken during load changes or under fluctuating load conditions are of questionable value for evaluating efficiency.

The operator's log should contain the following types of information:

- General data to establish unit output
  - steam flow rate, pressure, and temperature
  - feedwater temperature
- Firing system data
  - fuel type (in multi-fuel boilers) and characteristics
  - fuel flow rate
  - oil or gas supply pressure
  - pressure at burners
  - fuel temperature
  - burner damper settings
  - windbox-to-furnace air pressure differential
  - other special system data unique to particular installation
- Air flow indication
  - air preheater inlet oxygen content
  - stack oxygen content
  - optional - air flow pattern, forced draft fan damper position, forced draft fan horsepower requirements

- Flue gas and air temperatures
  - boiler outlet gas
  - economizer or air heater outlet gas
  - air temperature to air heater
- Combustible indicators
  - carbon monoxide levels
  - stack appearance
  - flame appearance
- Air and flue gas pressures
  - forced draft fan discharge
  - furnace outlet
  - boiler outlet
  - economizer differential
  - air heater air and gas side differential
- Unusual conditions
  - steam leaks
  - abnormal vibration or noise
  - equipment malfunctions
  - excessive makeup water
- Blowdown operation
- Sootblower operation
- Safety-related items
  - water level
  - feed pump pressure
  - low water cut out (if applicable)

5.3 INSTRUMENTATION AND CONTROLS

Pressure, draft, temperature, and flow indicators should be calibrated and serviced routinely. Boiler efficiency will suffer if boiler controls do not operate properly. Regular inspection checks and maintenance are necessary to insure that all valves, linkages, control circuits, and safety locks operate properly.

Steam pressure, temperature, and flow along with air and fuel flow provide information on the operation of the control system in maintaining desired boiler operation at various loads. Drum level and feedwater flow indicators provide necessary information about the boiler water supply. Draft gauges can indicate fly-ash plugging of the boiler, economizer, or air heater passages. Gas and air temperature measurements also indicate the need for soot blower operation. Annunciators (audible alarms) are required to warn the operator of hazardous operating conditions.

Basic instruments for safe boiler control and for documentation of the operation are listed below. Additional instrumentation is also available.

	Indicator	Recorder	Integrator
Boiler outlet pressure	X	X	
Superheater outlet steam temperature		X	
Steam flow		X	0
Total fuel flow		X	
Total air flow		X	
Individual fuel flow		0	0
Oxygen analyzer		0	
Combustibles analyzer		0	
Drum level	X	X	
Feedwater flow		0	0
Draft gauges	X		
Air and gas temperature	X	0	
Feedwater temperature	X		
Annunciator (audible alarms)	X		

X = Required
0 = Optional

5.4 ADDITIONAL CONSIDERATIONS IN A BOILER MAINTENANCE PROGRAM

Important elements of a boiler maintenance program include establishing a systematic approach and having operation and maintenance manuals, handbooks, and equipment instructions available to trained personnel who are equipped with all required maintenance tools, facilities, and parts. The best guide in establishing a systematic approach to maintenance is past experience. As it progresses, the program itself will develop experience and provide feedback that will help to improve the program. Checklists will help to establish inspection and maintenance routines. Records in the form of reminder cards or log sheets should also be maintained for individual equipment items in order to schedule upcoming maintenance and to document completed maintenance. Entries should indicate maintenance dates and descriptions; who performed the maintenance; and parts that were replaced, repaired, or cleaned. Parts lists that indicate part numbers and describe major items are also useful. These records are especially important in preventive maintenance where the use of periodic and routine cleaning, replacement, and adjustment focuses on reducing the chances of equipment failure or deteriorating performance. In setting up the maintenance system and procedures, full use should be made of instruction manuals and handbooks. These publications frequently give detailed information on procedures, tools, and facilities that are needed.

Correct tools and working facilities are important. Precision parts such as oil gun tips and burners can be easily damaged when removing deposits or encrusted carbon. Damage to sealing surfaces and fuel passages during cleaning or by dropping onto hard or dirty surfaces can result in leaks, inefficiency, and malfunctions.

Boiler equipment maintenance should be clearly assigned to reliable, thoroughly trained personnel. Whenever possible maintenance responsibility should remain in-house. In some cases outside maintenance contracts may be more economical. However, contracts for regular maintenance of major equipment seldom cover routine inspections and repairs that can result in important efficiency improvements. Thus, even if major items are covered by contract, a responsible person in-house should conduct general inspection and maintenance of the installation. Appendix E presents checklists to establish periodic inspection and maintenance routines on daily, weekly, monthly, and annual bases. These lists can be used to help custom design suitable checklists, reminder cards, and logsheets.

REFERENCES

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APPENDIX A

INSTRUMENTATION FOR FLUE GAS MEASUREMENTS

The adjustment procedures outlined in Section 4 require the measurement of the temperature, the oxygen (or carbon monoxide) and the carbon monoxide (or combustible) content of the stack gas. Smoke shade measurements are also useful in detecting incomplete combustion in oil-fired boilers. There is a wide variation in the sophistication, complexity and capability of the instruments available to make these measurements. Choices vary progressively from simple, hand-held instruments to panel-mounted recording devices to instruments that provide feedback and automatic control of the combustion process. Portable instruments are available that use either electronic or chemical principles to measure the concentrations of one or more flue gas constituents. Both portable and panel mounted instruments are available.

The selection of an instrumentation system depends largely upon the size of the boiler facility. For ongoing combustion spot checks and continuous boiler performance monitoring, particularly at the larger or multi-boiler facilities, more sophisticated instrumentation warrants serious consideration since the cost of instrumentation may be insignificant when compared to the fuel savings that can be obtained. However, portable instruments are entirely adequate for performing the adjustment procedures in this manual.

The following pages describe a cross-section of available instrumentation. The descriptions do not endorse any particular instrument, brand, or manufacturer, and are presented only to show the variety of available instruments.

CARBON MONOXIDE COMBUSTION TEST KITS AND ANALYZERS

Flue gas (combustion) test kits generally include an oxygen or carbon dioxide analyzer, a draft gage, a smoke tester, and a thermometer. The kits are portable, convenient to use and generally cost less than 500 dollars. One test kit manufacturer claims a carbon monoxide measurement accuracy of ± 0.5

percent (oxygen is not measured). The kit includes a carbon monoxide indicator, a draft gage, a dial thermometer, a smoke density measurement device, a stack piercing awl, hole plugs, a combustion efficiency slide rule, instructions, a carrying case, etc.; the test kit costs approximately 200 dollars.

Combustion efficiency analyzers are available which measure and display oxygen content, stack temperature, and combustion efficiency. These portable analyzers operate on batteries, sell for less than 1000 dollars, and include a stack probe with built-in oxygen and temperature sensors and a connecting cable. A more refined model that also measures smoke shade costs approximately 1300 dollars.

A portable AC/battery operated device is marketed which measures oxygen, carbon monoxide, smoke, and stack temperature using a single probe. Measured values are displayed in digital form; combustion efficiency is also calculated and displayed. The cost of this combustion efficiency tester/computer varies from approximately 1500 dollars (for a single liquid or gaseous fuel) to 2500 dollars for a model that can be used on all common liquid or gaseous fuels.

FLUE GAS ANALYZERS (PORTABLE)

The standard Orsat type apparatus is portable and measures oxygen, carbon monoxide, and carbon monoxide using wet chemistry. An Orsat analysis is accurate but requires skill, practice and maintenance. The cost of the apparatus is about 500 dollars; it is available from most laboratory equipment suppliers.

OXYGEN ANALYZERS

Oxygen analyzers are available as portable or panel mounted devices that use wet chemistry or other detection principles. Those operating on the chemical absorption principle are simple to use, portable, and accurate and can be purchased for approximately 100 dollars. Portable units are also available that use paramagnetic or other measurement principles. The units display measured values on a digital meter or percent scale. These instruments cost approximately 1000 dollars. Panel mounted AC powered instruments usually come with a strip chart recorder and cost over 1000 dollars.

CARBON DIOXIDE ANALYZERS

Portable, easy to use, wet-chemical absorbent-type carbon monoxide testers are available for approximately 150 dollars. Panel-mounted instruments that employ infrared absorption generally cost over 1000 dollars and may come with accessories such as a strip chart recorder and a controller.

CARBON MONOXIDE ANALYZERS

Indicator tube type carbon monoxide analyzers use disposable, color-sensitive chemicals in tubes and a calibrated sampling pump to provide a length-of-stain carbon monoxide reading. The instruments are very portable and fairly accurate; they sell for approximately 100 dollars. Panel mounted instruments of the infrared absorption type generally cost over 1000 dollars depending on accessories (chart recorder, controller, etc.).

COMBUSTION OXYGEN AND CARBON MONOXIDE (OR COMBUSTIBLE) ANALYZERS

Portable analyzers are available that measure both oxygen and carbon monoxide (or combustible) concentrations and display the values on separate meters or digital readouts. These battery operated instruments generally use electrochemical sensors. They contain an integral pump-sampling system and provide rapid, accurate readings. These portable instruments cost approximately 2200 dollars. Panel-mounted analyzers are also available for continuous measurement applications.

SMOKE TESTERS

Smoke testers generally use a calibrated hand pump to draw flue gas through a filter paper for smoke spot determination. The stain is compared with a set of standard smoke spot numbers (SSN). The kit contains a scale for evaluating SSN values from 0 to 9 on the Bacharach or ASTM scale. The device is rugged, portable, and reliable; it requires no calibration and sells for about 100 dollars.

AIR PRESSURE GAGES

Manometers and mechanical (aneroid) gages for measuring furnace or stack draft are simple, accurate, and portable. They are readily available from most laboratory supply houses for 50 dollars or less.

STACK TEMPERATURES

Stack temperature measurements can be made with dial thermometers, liquid thermometers, or other temperature sensing devices. Although liquid thermometers generally have greater accuracy, dial thermometers are more rugged. Dial thermometers with a suitable range for stack temperature measurement generally cost less than 50 dollars.

APPENDIX B

ILLUSTRATIVE EXAMPLE - USE OF TEST DATA FROM THE MINIMUM OXYGEN ADJUSTMENT PROCEDURE

The following hypothetical example illustrates the use of test data from the procedure described in Section 4.3.4. For illustrative purposes assume that the data in the following table were recorded during Steps 2 through 5 of the procedure.

Procedure step (see Section 4.3.4)	Stack readings		
	Oxygen, %	Carbon monoxide, ppm	Temperature, °F
Step 2 (Baseline condition)	7.4	95	475
Step 3	8.6	90	480
Step 4 (a)	5.8	98	460
(b)	4.7	100	456
(c)	3.8	105	452
(d)	3.3	130	445
(e)	2.6	220	441
(f)	2.1	360	435
(g)	1.6	520	435
Step 5	1.0	800	432
Step 8	3.0	160	440

In this example the baseline oxygen concentration before adjustment was 7.4 percent (Step 2). In following the procedure the combustion air flow was increased (Step 3) and then reduced in small increments (Step 4) until carbon monoxide measurements indicated a rapid rise in carbon monoxide concentration (Step 5). After each adjustment the boiler was allowed to stabilize before readings were taken. The plot of carbon monoxide and oxygen concentrations is shown in Figure B-1.

The minimum oxygen level (carbon monoxide limit of 400 ppm) obtained from Figure B-1 is 2.0 percent. The boiler manufacturer recommends an excess

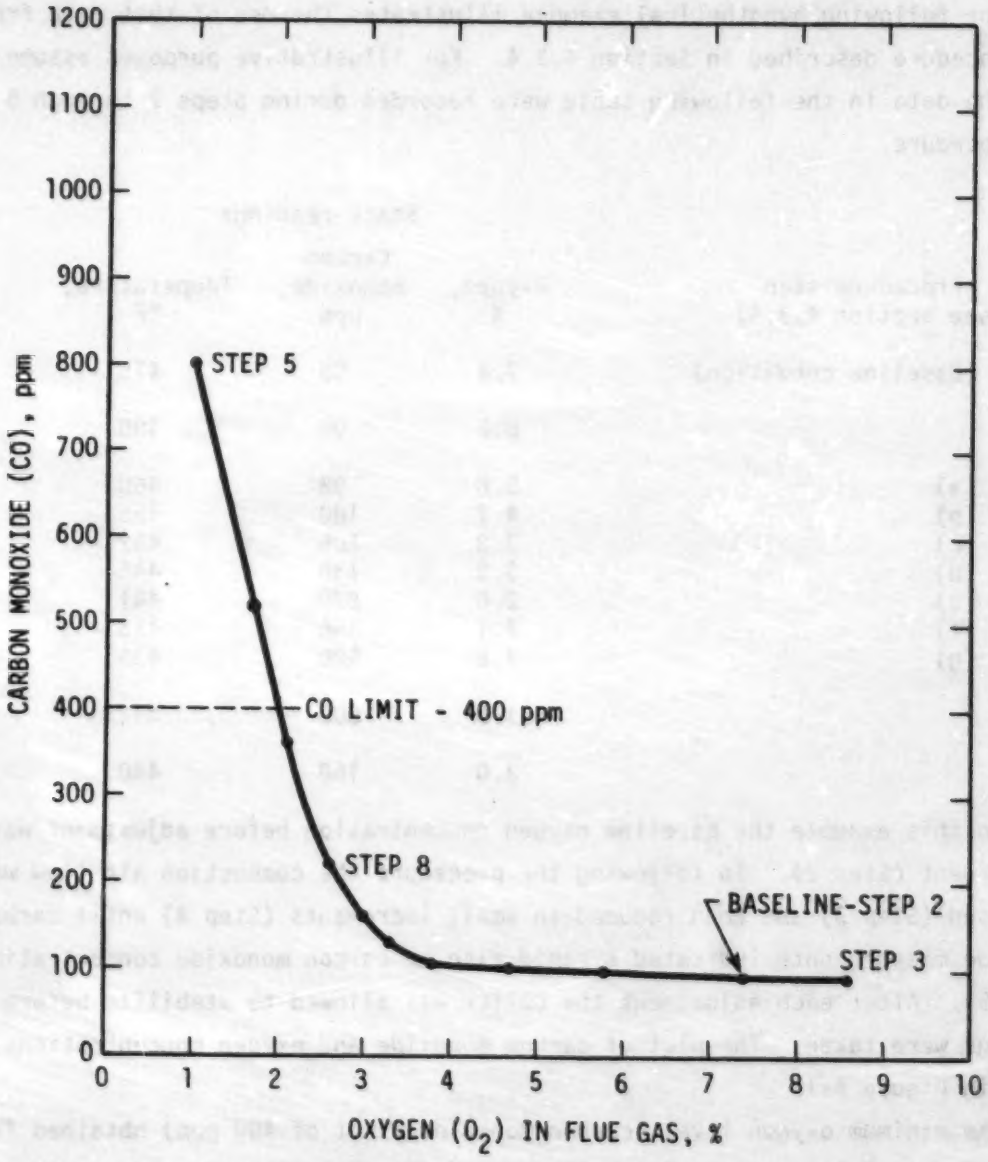


Figure B-1. Example data: carbon monoxide (ppm) versus oxygen (%).

oxygen level of 2.5 percent for this model. However, the curve for this particular boiler installation has a steep characteristic; as oxygen is decreased below 3 percent the carbon monoxide concentration rises rapidly. Suppose also that this boiler is subject to considerable fluctuations in load. The steep curve characteristic, load swings, and changing atmospheric conditions are factors in the selection of an adequate oxygen safety margin. If a 1.0 percent safety margin is selected, the lowest practical operating level becomes 3.0 percent oxygen. Considering the above factors this is reasonably close to the manufacturer's recommendation. The boiler controls are then adjusted to the 3.0 percent oxygen level, and a final set of readings is taken (Step 8).

The calculation methods in Appendix C can be used to determine the combustion efficiency improvement and the fuel savings that result from adjustment for low excess oxygen operation. For example, using Figure C-2 for a boiler fired with no. 2 oil and the data for the baseline reading (Step 2 - 7.4 percent oxygen and 475°F) the combustion efficiency before oxygen optimization was 82.3 percent. The final oxygen setting (Step 8 - 3.0 percent oxygen and 440°F) increases the combustion efficiency to 85.7 percent - an improvement of 3.4 percent. The fuel savings due to the improved efficiency is 4 percent (3.4 x 100/85.7 = 4 percent).

APPENDIX C

COMBUSTION EFFICIENCY

The approximate boiler combustion efficiency can be quickly determined using Figures C-1, C-2 and C-3. To use these figures the temperature and oxygen (or carbon dioxide) content of the flue gas must be known. Graphs are presented for boilers fired with natural gas (Figure C-1), Number 2 oil (Figure C-2), and Number 6 oil (Figure C-3). In those instances where the carbon dioxide rather than the oxygen content is known Figure C-4 can be used to convert the carbon dioxide reading to an equivalent oxygen value for use in the graphs. Figure C-4 can also be used to determine the percent excess air represented by a given oxygen or carbon dioxide value.

To determine combustion efficiency select the graph for the appropriate fuel and enter the graph along the "oxygen in flue gas" axis. Proceed vertically until the proper flue gas temperature line is intersected, pivot and move horizontally to the combustion efficiency axis.

For example assume the stack measurements for a boiler fired with No. 2 oil are 7.4 percent oxygen and 475°F - the same as the baseline reading in the illustration in Appendix B. Use Figure C-2 and enter the oxygen content axis at 7.4 percent proceed vertically to 475°F, pivot, and move horizontally to read 82.3 percent as the approximate combustion efficiency. In the Appendix B example the flue gas readings after adjustment for low excess oxygen operation were 3 percent oxygen and 440°F. The improved efficiency from the No. 2 oil chart is 85.7 percent.

FUEL SAVINGS

The estimated fuel savings as a result of combustion efficiency improvement can be calculated using the following equation:

$$\text{Estimated fuel savings} = \frac{(\text{Improved efficiency} - \text{original efficiency})}{(\text{Improved efficiency})} \times 100\%$$

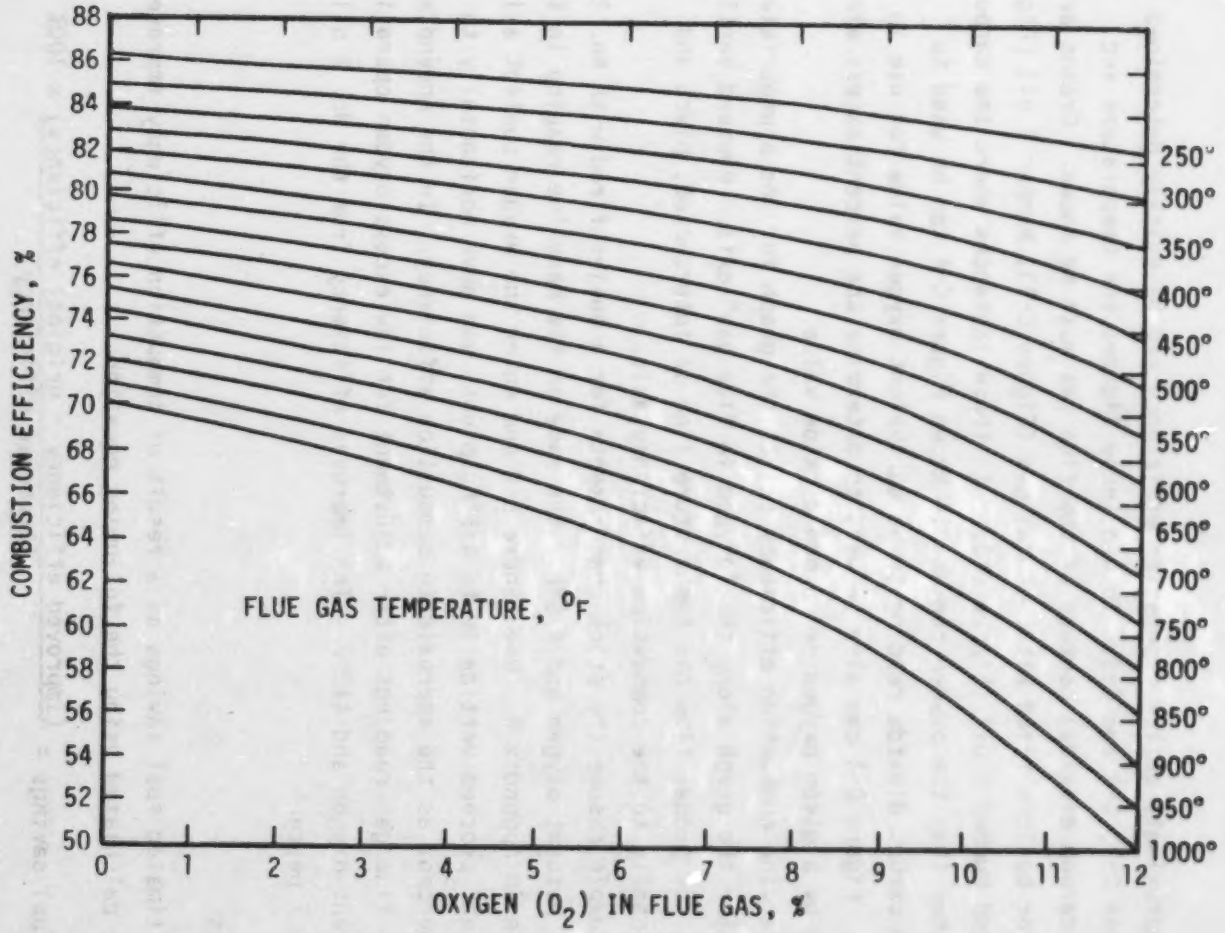


Figure C-1. Combustion efficiency as a function of stack gas temperature and flue gas oxygen content for natural gas firing.

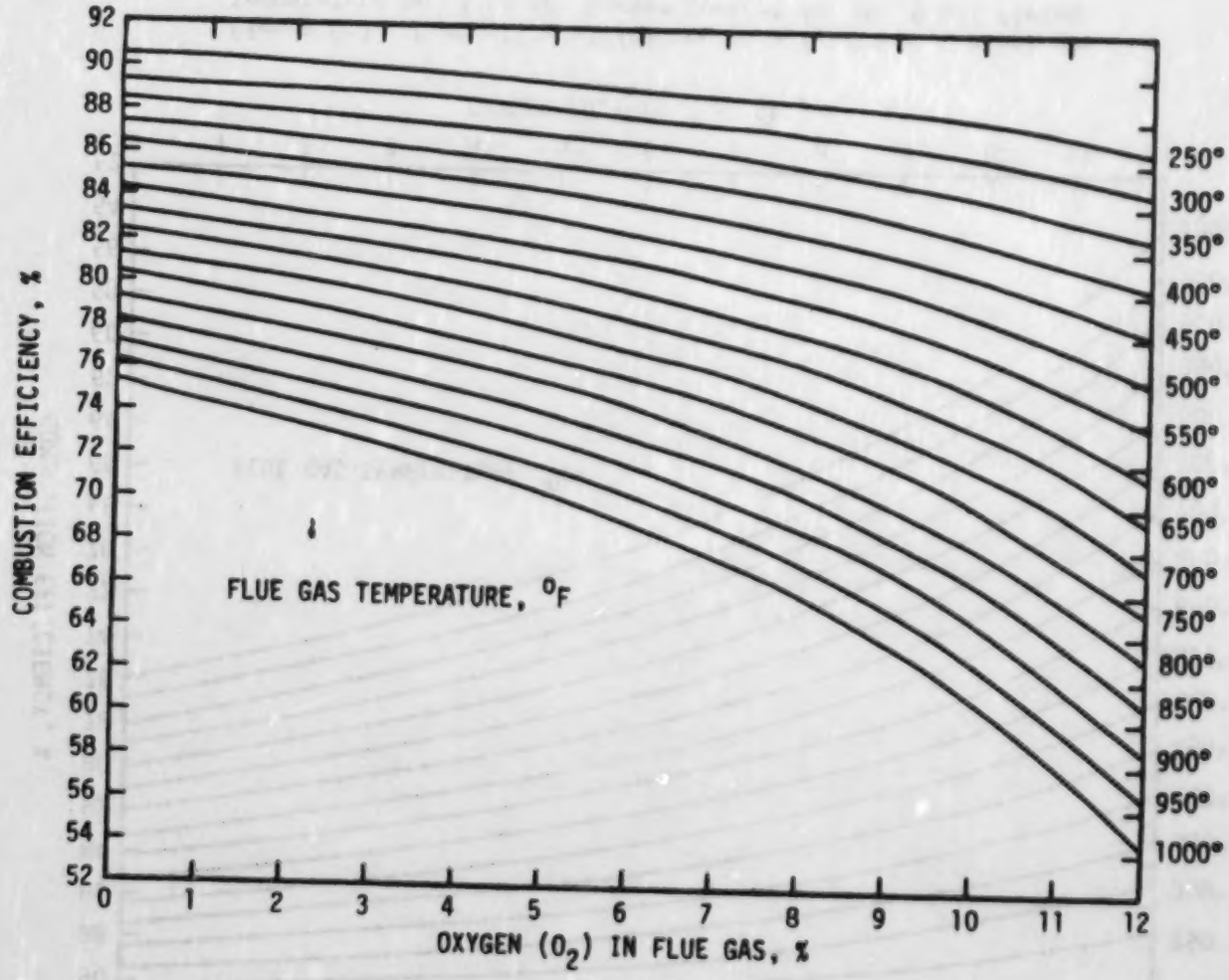


Figure C-2. Combustion efficiency as a function of stack gas temperature and flue gas oxygen content for No. 2 oil firing.

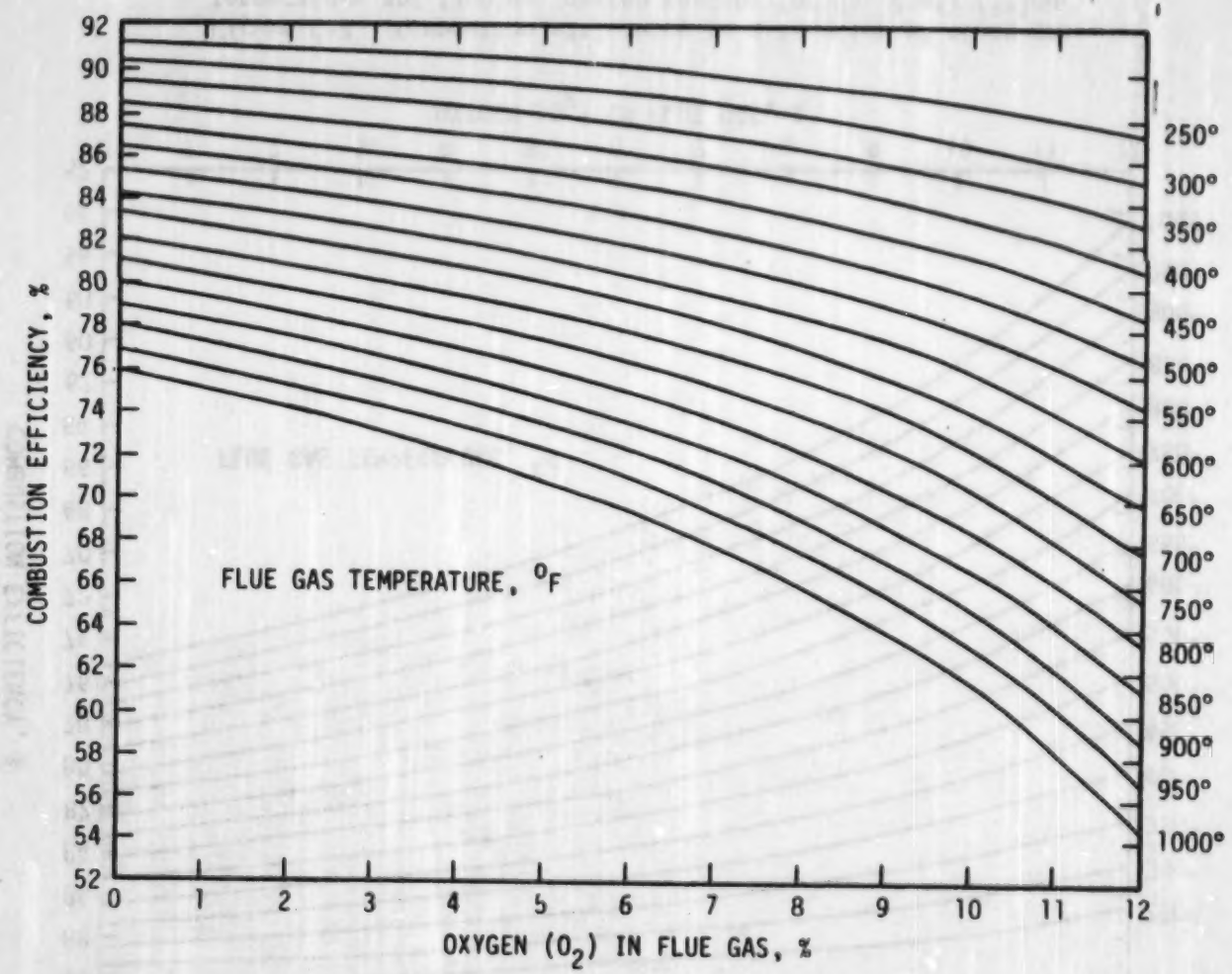


Figure C-3. Combustion efficiency as a function of stack gas temperature and flue gas oxygen content for No. 6 oil firing.

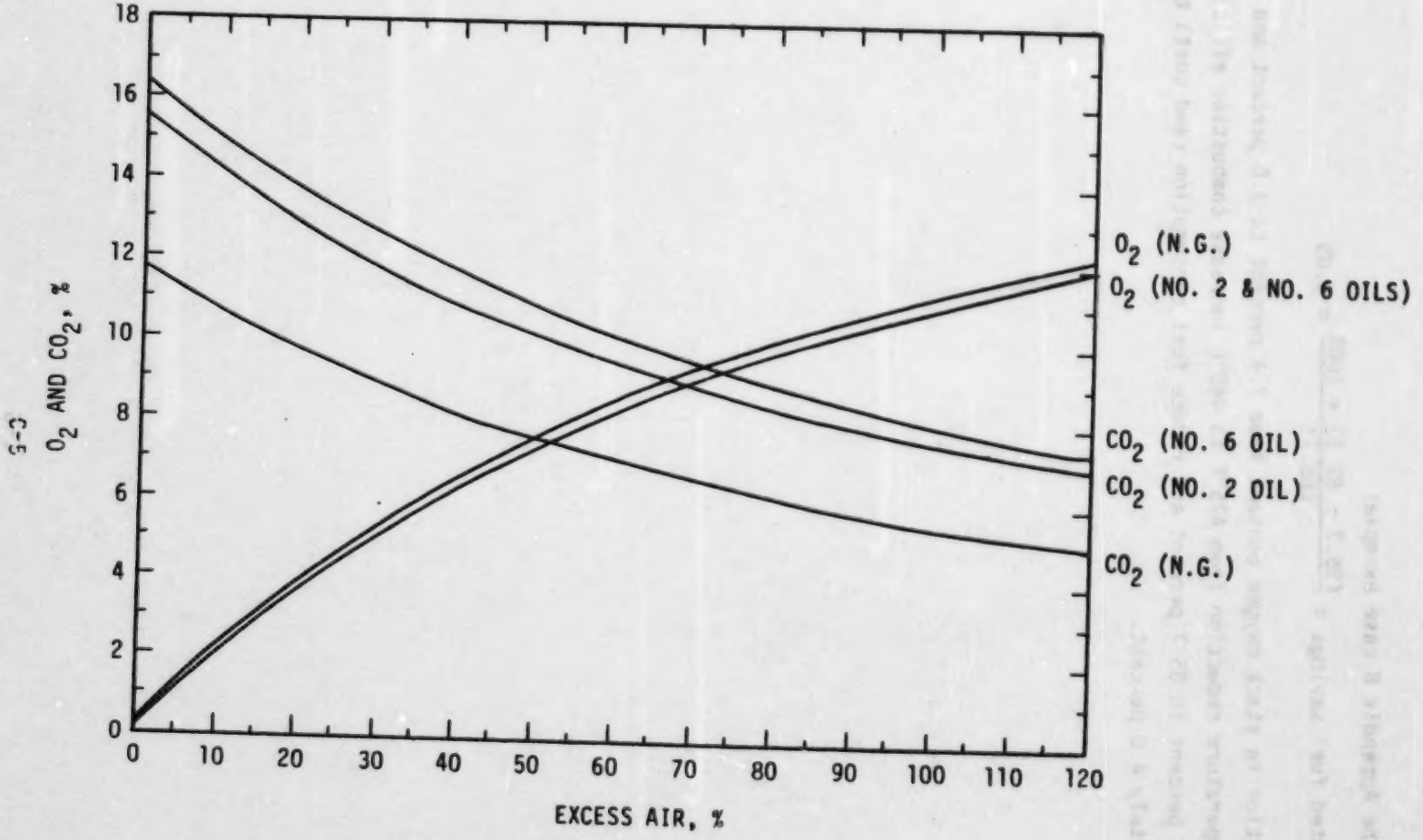


Figure C-4. Comparative relationship between boiler excess air and flue gas concentrations of oxygen and carbon dioxide when burning oil or natural gas.

In the Appendix B case example:

$$\text{Estimated fuel savings} = \frac{(85.7 - 82.3) \times 100\%}{(85.7)} = 4.0\%$$

The reduction in stack oxygen content from 7.4 percent to 3.0 percent and the stack temperature reduction from 475°F to 440°F increase combustion efficiency from 82.3 percent to 85.7 percent and reduce fuel consumption (and cost) by approximately 4.0 percent.

APPENDIX D

TRACKING PROCEDURE FOR THE CONTINUING EVALUATION OF BOILER PERFORMANCE

The full benefits of boiler adjustment can only be realized if steps are taken to insure that any improvements in boiler efficiency, fuel consumption and emissions are maintained. Tracking the day-to-day boiler performance and noting performance trends provides early detection of deteriorating boiler conditions so that corrective action can be taken before fuel waste or extensive maintenance is required. The tracking procedure presented here can be easily implemented with a minimum of time, equipment and effort. Operators will find the procedure useful as a monitoring tool in establishing and maintaining emission reduction gains, fuel use savings and reliable, efficient boiler operation.

The tracking procedure consists of three step-wise segments - the initial one-time design of data forms and a records handling/filing system, the repeated and periodic on-site collection of data, and the final step - comparison, evaluation and use of collected data.

PLANT FILES AND DATA FORMS

The use of prepared forms and a simple filing system will ensure that essential data is collected, properly recorded and securely stored. It is suggested that at a minimum the records retention and file system should include:

- Plant files (folder) that identify the individual plant (or facility) by name, location, owner, boiler operator/phone, number of boilers/boiler ID designations, etc.

- Boiler fact and data record sheets. Within the plant file one each of a boiler fact sheet and data record sheet should be provided for each plant boiler. The fact sheet should list such information as the boiler number (plant ID), make, type, rated capacity, fuel type(s), boiler operator name/phone, etc. The data record (or tracking) sheet is used to record key boiler operating and combustion parameters observed or measured during each of the periodic inspections. Examples of a boiler fact sheet and a data record sheet are shown in Figures D-1 and D-1, respectively.

DATA COLLECTION STEPS

The necessary data for implementing the tracking procedure can be properly collected and recorded by following the steps listed below:

1. Determine the normal (usual) operating load.

   This step is extremely important with respect to tracking procedure reliability and the inferences to be drawn from comparison with future data readings. Measurements taken at different load conditions can vary considerably, do not correlate well and the variance can mask any differences or trends that occur. All future measurements must be made at the same or near-equal load conditions in order that meaningful comparisons can be made.

2. Operate boiler at normal load and await steady load conditions before making observations and measurements. Steady conditions are usually indicated by stable stack temperature, steam pressure and oxygen (or carbon dioxide) flue gas content.

3. Analyze the composition of stack (exhaust) gases for oxygen (O_2) or carbon dioxide (CO_2) content and presence of combustibles - hydrocarbon (HC) or carbon monoxide (CO).

4. Record measurements and observations on the boiler data record sheet.

   - Combustion air temperature - degrees Fahrenheit (°F)
   - Flue stack gas temperature - degrees Fahrenheit (°F)
   - Flue gas composition from step 3 above - percent (%) of O_2 and/or CO_2 and parts per million (ppm) of CO and/or HC.
   - Boiler operating load - percent (%)
   - Steam pressure - pounds per square inch gauge (psig)
   - Steam temperature - degrees Fahrenheit (°F)

5. Record any appropriate comments or observations that may be helpful or useful in data evaluation (flame appearance, unusual conditions or events, new permanent changes, etc.).

BOILER FACT SHEET

Boiler Operator: _____ Phone: _____ Date: _____

Plant name: _____ Industry type: _____

Address: _____

No. of boilers at location: _____

Boiler ID: _____ Make: _____ Type: _____

Rated capacity: _____ 10^6 Btu/h Normal operating capacity _____ 10^6 Btu/h

Fuel(s) data:

° Type(s): _____, _____

° Heating values: _____, _____

Steam data:

° Rated maximum _____ lb/h

° Normal (actual) _____ lb/h

° Pressure _____ psig

° Temperature _____ °F

Steam use is for (comfort heating, process, etc.) _____

_____

_____

Boiler operating data:

° Year round ( ), seasonal ( ) and during months of _____ through _____

° Base load unit ( ), swing load unit ( )

° Alone ( ), in conjunction with ____ other boilers ( )

° Burner type: _____

° Blowdown is continuous ( ), batch ( )

° Water softening system type: _____

° Water quality testing/control is done: in-house ( ), by contract ( ) -

_____

° Maintenance is: in-house ( ), by contract ( ) - _____

° Annual maintenance/tune-up, etc. is done: in-house ( ), by contract ( ) during the month of _____

Figure D-1. Example of Boiler Fact Sheet.

BOILER DATA RECORD SHEET

Plant: _____ Boiler ID _____

Test date									
Load	%								
Steam pressure	psig								
Steam temperature	°F								
Combustion air temp.	°F								
Flue gas temp.	°F								
CO_2 - flue gas	%								
O_2 - flue gas	%								
CO - flue gas	ppm								
Combustion effeciency	%								

Date	Relevant comments (flame appearance, furnace conditions, new permanent changes, etc.)

Figure D-2. Example of Boiler Data Record Sheet.

6. Determine and record the combustion efficiency using the measured data. The data for flue gas temperature and oxygen content are used to determine combustion efficiency from the fuel-specific curves of Figures C-1 through C-3 in Appendix C. In the event CO_2 is measured rather than O_2, Figure C-4 can be used to convert CO_2 percent to equivalent O_2 percent for use in Figures C-1 through C-3.

7. Plot selected key data to show trends. An example format for graph plots is shown in Figure D-3.

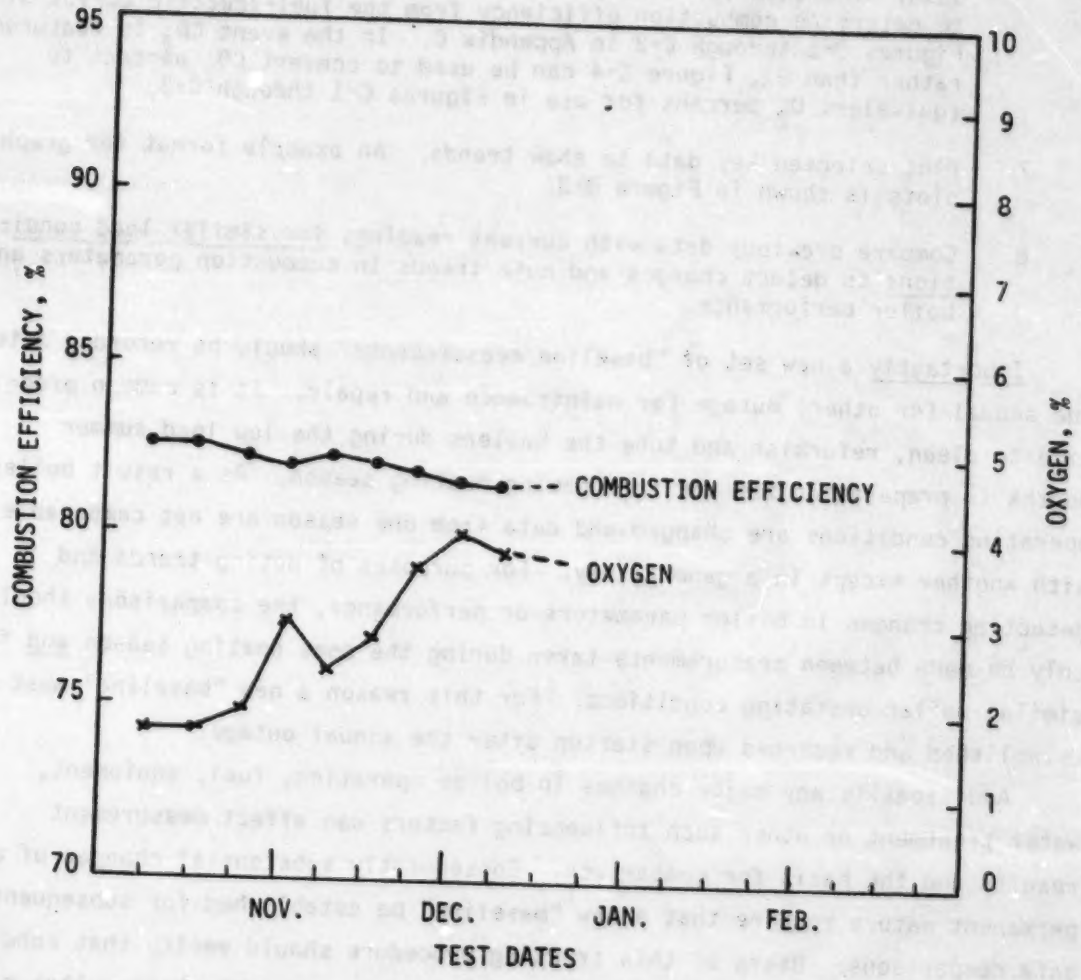
8. Compare previous data with current readings for similar load conditions to detect changes and note trends in combustion parameters and boiler performance.

Importantly a new set of "baseline measurements" should be recorded after the annual (or other) outage for maintenance and repair. It is common practice to clean, refurbish and tune the boilers during the low load summer months in preparation for the forthcoming heating season. As a result boiler operating conditions are changed and data from one season are not comparable with another except in a general way. For purposes of noting trends and detecting changes in boiler parameters or performance, the comparisons should only be made between measurements taken during the same heating season and for similar boiler operating conditions. For this reason a new "baseline" must be established and recorded upon startup after the annual outage.

Additionally any major changes in boiler operation, fuel, equipment, water treatment or other such influencing factors can affect measurement results and the basis for comparison. Consequently substantial changes of a permanent nature require that a new "baseline" be established for subsequent data comparisons. Users of this tracking procedure should verify that conditions remain the same and should always be alert to any such changes that may have occurred since a previous data collection period.

DATA USE

A systematic record of data collected during periodic inspections, combustion efficiency spot checks and boiler log entries can yield an information base from which trends in boiler combustion efficiency and operating parameters can be noted. The tracking procedure uses this data base to monitor



NOTE: The plots shown are illustrative only. Other measurements such as flue gas temperature, CO_2, and CO can also be plotted to show trends with time.

Figure D-3. Example plots of Boiler Tracking Data.

boiler operations, discover changes with time and detect early-on any deterioration in boiler performance. Early detection and corrective action can minimize or forestall increases in heat loss, fuel waste, malfunction and serious repair/maintenance problems that otherwise might occur in the absence of a systematic scheme for observing, recording and analyzing boiler performance and operational data.

APPENDIX E

EXAMPLE INSPECTION/MAINTENANCE CHECKLISTS

Daily Checks and Maintenance Requirements

At a minimum, the following checks should be done on a daily basis. More frequent checks are advisable.

- Test low water fuel cut-off.
- Test water level control.
- Test and then blow down water column and gauge glass (every shift).
- Check water level stability, fuel pump pressure, feedwater and condensate temperature, and steam pressure.
- Check feedwater system - examine traps, make-up float valves, check valves, and condensate tank. Blow down all float chambers and check for leaks.
- Boiler blowdown - for manual blowdown the frequency and quantity of blowdown depends on the feedwater condition. For continuous automatic blowdown check system operation and minimize excessive blowdown.
- Check fuel supply systems, main fuel valves, and burner controls for proper operation. Check regulator pressure (gas-firing), fuel pressure, flow rate, oil temperature, and atomizer steam or air pressure (oil-firing).
- Check flue gas temperature at two different settings and compare with standard established via minimum O_2 adjustment procedure.
- Check O_2 analyzer reading (if so equipped) and compare with test data.
- Check flame scanner lens, and clean as required.
- Visually inspect combustion chamber and flame profile.
- Check all instruments.

Weekly Checks and Maintenance Requirements

- Clean combustion air blower wheels.
- Clean air distribution plates.
- Clean oil nozzles and atomizing air flow (oil-fired).
- Clean and inspect condition of pilot and burner assemblies.
- Check safety relief valve for operation and leaks.
- Check flame failure and start-up controls.
- Check feedwater expansion regulators and check for leaks.
- Inspect air cleaners and replace filter media as necessary.
- Check exhaust gas composition (O_2 and CO_2, and CO concentrations) and stack temperature. Compare to O_2 optimization test data at same settings.
- Check fuel level in oil tanks.
- Check all drive belts for tension and wear.

Annual Check and Maintenance Requirements

- Inspect the general cleanliness/conditions of the fire (gas) side and water side of the boiler. Inspect for deposits on furnace walls, evidence of wall heating (bulges or tube swelling), deposits (scale) on heat transfer surfaces, condition of baffles, refractory, etc. Clean radiant heat transfer surfaces, boiler tube banks, economizers, air heaters, etc. Repair as necessary.
- Clean or recondition fuel system - pumps, filters, burners, pilots, oil preheaters, storage tanks, etc. Inspect and clean burner tips, diffusers, spinner plates, etc. Check tips for wear, nicks, and cracks. Inspect and clean burner throat refractory and air registers.
- Inspect insulation of boiler surfaces, ducts, steam lines etc., and repair as necessary.
- Inspect boiler for casing leaks (smoke tests).
- Inspect air and gas ducts, air registers, dampers, and stack for leaks, deformation, corrosion, etc.
- Clean and inspect fans and inlet screens. Examine scroll, rotor, wear plates, seals, and dampers for erosion, cleanliness, alignment, and operation.

- Dismantle, clean, inspect, calibrate, align, and test the combustion control system.

- Clean and inspect the feedwater system. Clean condensate receiver and aeration systems, clean and recondition feedwater pumps, etc. Disconnect all linkages, and overhaul and calibrate all parts of the feedwater regulating system.

- Clean and inspect the electrical systems. Clean all terminals and check electronic controls and switches.

- Clean and inspect all hydraulic/pneumatic valves and check for proper operation, alignment, and leaks.

- Remove, clean, and recondition the safety/relief valve system.

- Replace manhole and handhole gaskets.

- Change gear case lubricants, and lubricate all bearings as required.

- Test all safety devices.

- Tune the boiler for low excess oxygen operation. Record data for subsequent comparison and adjustment.

Other Periodic Checks and Maintenance Requirements

- Conduct detailed burner check at least four times per year.

- Dismantle and clean low water cut-off controls every six months.

- Every three to four months have automated combustion controls (meters, activators, and controllers) checked by competent service organizations.